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UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

WATER-SUPPLY PAPER 219

GROUND WATERS AND IRRIGATION ENTERPRISES

IN THE

FOOTHILL BELT, SOUTHERN CALIFORNIA

BY

WALTER C. MENDENHALL

WASHINGTON
GOVERNMENT PRINTING OFFICE
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GROUND WATERS AND IRRIGATION ENTERPRISES IN THE FOOTHILL BELT OF SOUTHERN CALIFORNIA.

By Walter C. Mendenhall.

INTRODUCTION.

In midsummer, 1903, field work was begun on a series of studies of the conditions under which the ground waters of southern California occur. During the preceding decade the inadequacy of surface waters, the perfection of pumping machinery, the development of cheap fuel and electrical power, and the discovery of the wide distribution and accessibility of ground waters combined to make these of increasing importance in the irrigation of the intensively cultivated horticultural districts which have made this portion of the State famous. Even the largest of the systems of irrigation, which a few years ago secured their waters wholly from the mountain canyons, now usually have subsidiary pumping plants, which are depended on to keep up the supply during the summer and fall, when the streams are lowest; and in addition to plants of this character, many companies have been organized that depend entirely on pumped or artesian waters. So extensive has been this development that a conservative estimate indicates that the proportion of underground water to surface water now used during the late summer period after dry winters, when the surface supply is lowest and the pumps are busiest, is as 3 or 4 to 1.

Obviously a resource which has become so important to the continued welfare of so rich a district is worthy of careful study. Such a study is now under way, and its results are being made known through a number of water-supply papers that are being issued by the United States Geological Survey. The earliest of these to be prepared for distribution were a series of three (Nos. 137, 138, and 139) relating to the coastal plain which lies between the Coast Range and the Pacific Ocean. These papers did not embody close geologic determinations, but were rather records of the developments of underground waters which had taken place at the time of their issue, with some discussion of the effects of those developments in the region treated in them.

The more important data were graphically presented in maps and tables. A fourth paper (No. 142), on the San Bernardino basin, was more complete and critical, and contained, in addition to the essential hydrographic data, such significant geologic and economic information as had been brought out in the course of a rather careful general study of the valley.

The present paper is intended to continue the presentation of evidence and conclusions which are of value to water users for the important region that lies along the south base of the San Gabriel Mountains from Cucamonga westward to Los Angeles. This belt embraces a small area in the extreme western part of San Bernardino County, but lies for the most part within Los Angeles County. It includes the important communities about Ontario, Pomona, Lordsburg, San Dimas, Covina, Glendora, Monrovia, and Pasadena, and is conveniently and appropriately designated the "foothill belt." Within this area, which comprises only about 450 square miles of lowlands, there are between 55,000 and 60,000 acres of irrigated lands (exclusive of municipalities), a large proportion being in citrus fruits. This acreage ranges in value from $200 to $2,000 an acre, and may be conservatively estimated to be worth $20,000,000 or $25,000,000. In the same area there are about 40 flowing wells and nearly 400 pumping plants, representing an investment of at least $1,000,000 in wells and plants alone. There is, of course, an additional heavy investment in the connecting distributing systems. It is estimated that the pumping plants supply the equivalent of 80 to 100 second-feet of water, continuous flow, used largely for irrigation. This output is not regularly distributed throughout the year, but is largely concentrated in the dry months of July, August, and September, during which, after winters of light rainfall, the production of underground waters amounts to 300 second-feet or more.

GEOGRAPHY.

The valley of southern California is a complex lowland which lies at the south base of the San Gabriel and San Bernardino ranges, opens directly westward to the Pacific, and communicates with the Mohave and Colorado deserts through Cajon and San Gorgonio passes. Its southern boundary is irregular, since in this direction finger-like extensions interdigitate with spurs of the Peninsula Range, whose main mass lies to the south; but its eastern, western, and northern boundaries are perfectly definite. The entire area of this horticultural and productive center of southern California is not more than about 3,000 square miles, yet in wealth, population, and teeming industry it is of more importance than all the rest of the State south of the Tehachapi Mountains.

A, B. PANORAMIC VIEW OF R

C, D. PANORAMIC VIEW OF PALOMARES CIÉNAGA LANDS AN

ROYO SECO ABOVE DEVILS GATE.

THE SAN GABRIEL RANGE NORTH OF THE CUCAMONGA PLAINS.

The foothill belt is that part of the valley of southern California which lies along the base of the San Gabriels from Pasadena to the western edge of the San Bernardino Valley. It includes the greater part of two lowland areas, the Cucamonga Plains and the San Gabriel Valley, and the divide between them. The divide is a broad, low, interrupted pass that separates a northern outlier of the Coast Range in the vicinity of Lordsburg from the San Gabriel Range. This pass and the valley of San Jose Creek, just south of it, give the most direct lines of communication between Los Angeles and the easterly portions of the valley of southern California, about Riverside, San Bernardino, and Redlands. The Cucamonga Plains, forming the eastern section of the foothill belt, constitute a wide area of valley land, which slopes from an elevation of 2,000 feet on the upper portions of the great alluvial cones at the base of the San Gabriel Range to 500 feet at Rincon, where Santa Ana River enters its lower canyon through the Santa Ana Mountains. Eastward the plains merge without intervening physical barriers into the San Bernardino Valley.

Westward from the pass at Lordsburg the San Gabriel Valley opens. It is a rudely semicircular depression, whose base is the San Gabriel Range and whose encircling hills are the low and scattered representatives of the Coast Range. San Gabriel River crosses this semicircle as a radius from the mouth of its mountain canyon above Azusa to the Paso de Bartolo, through which it flows out upon the coastal plain. One other stream enters the San Gabriel Valley from the mountains and escapes from it by an independent canyon. This is Arroyo Seco (Pl. I, *A*, *B*), which hugs the extreme western edge of the valley, finally breaking through the hills there to join Los Angeles River at the inner edge of the coastal plain. All other streams that drain into the San Gabriel Valley from the mountains are tributary to San Gabriel River when all of their flow does not sink before reaching it.

The general surface aspect of this valley is like that of the Cucamonga Plains. The surface slopes gently, being steepest at the mountain base and flatter at a distance from it. San Gabriel Wash is the valley axis, and slopes are toward it from all directions. But in general the San Gabriel Valley slopes are less steep than those of the Cucamonga Plains, and there are within it, at the foot of the higher mountains, less extensive areas of lands too coarse and rough for cultivation.

All of this foothill belt, and many square miles of mountains north of it, are shown on three of the United States Geological Survey topographic sheets—the Cucamonga, the Pomona, and the Pasadena—drawn on a scale of about 1 mile to the inch.

GENERAL GEOLOGIC CONDITIONS.

The problems of the occurrence, the volume, the direction and rate of percolation, and the accessibility of the ground waters in any region are intimately related to the rock masses, their position, character, and attitude, and these are problems of geology. The study of ground waters, then, is in many of its phases an application of geologic principles and can not be carried out with thoroughness or success unless those elements of the geology which have a bearing on the problems are studied at the same time.

In order to make clear, therefore, the conditions which control the occurrence and circulation of the ground waters in the foothill belt, a résumé of the important geologic factors is given.

From the point of view of the water user the rock masses of the foothill belt fall into two very general classes, those which are water bearing and those which are not.

In the class of the rocks that are not water bearing are the diorites, schists, and gneisses of the San Gabriel Range and of some of the foothills. Among the latter are the Verdugo Mountains and the San Rafael Hills, and there are areas in the Santa Monica Mountains and the Puente Hills which are made up of the same dense, practically impervious rock. Such rocks are not absolutely dry. They are in places fractured and shattered, or are affected by cleavage and joint cracks in which water in small quantities may occur, but it is practically never sufficiently abundant to justify expenditures of capital in development work. Local water companies have at various times and places driven tunnels or bored wells in these rocks, but the result is invariably disappointing. The amount of water obtained does not compensate for the capital expended, and such developments are usually abandoned.

Another series of rocks, very different in origin and appearance, is also placed in this class. These rocks are the shales, sandstones, and conglomerates, usually of Tertiary age, which make up the greater part of the low hills that rise at some distance from the base of the San Gabriel Mountains. The greater part of the Puente Hills, all of the hills about Los Angeles and east of that city toward San Gabriel River, and the main mass of the Santa Monica Mountains are made up of rocks of this type.

These beds are sediments, finely stratified and folded, and they occasionally yield water in sufficient volume to be valuable. A group of deep wells west of Los Angeles, bored originally for oil, obtained water from these Tertiary sandstones. In a few wells it was under sufficient pressure to flow, but, like most waters from the oil-bearing beds, it is of rather poor quality, in that it generally carries a large proportion of alkaline salts in solution and is frequently charged also with sulphuretted hydrogen gas.

As compared with the supply in the gravel beds to be described shortly, these rock waters are negligible in quantity and wholly inferior in quality. From the practical point of view, therefore, the rocks in which they are found are to be considered as dry in this part of southern California, although here and there a successful well has been drilled in them. All these "dry" rocks have an important indirect function to perform in the storage of the ground waters, as they form the bottom and sides of the subterranean reservoirs and so confine the waters which saturate the loose gravels that fill them.

But in any study of conditions controlling underground-water supplies the important formation is the most recent one—the alluvial wash which fills the rock basins, absorbs the flood waters and the return irrigation waters, and yields these up again at lower points through springs of even flow or through artesian and pumped wells. This material is the very latest deposit in the foothill belt. It is composed exclusively of the wash from the heights which surround the lowlands. Of these heights the San Gabriel Mountains, because of their greater relief, are the most efficient and yield much the greatest amount of débris, in the coarsest condition. The lower hills south and east of the foothill belt yield comparatively insignificant amounts of relatively fine material; consequently the greatest accumulations of this alluvium are found along the bases of the higher mountains, where it is also the coarsest. But the alluvium itself is not a simple formation, which has all been deposited in one period. There are unmistakable evidences that it has originated at two different times, and that between these periods the mountain-making and valley-deepening forces were active, so that it is probable that the San Gabriel Range is higher now than when the first of this alluvium was laid down. This is a matter of importance to the water user, because the greater number of those mysterious "dikes" which are cited to account for the apparently erratic behavior of the underground circulation are due to the relations which exist between the earlier and later alluvial deposits. As a matter of convenience the alluvium first laid down will be spoken of as the earlier alluvium and that of the second period as the later alluvium.

Along the base of the San Gabriel Mountains, from Arroyo Seco eastward to the San Dimas, there are a number of benches, capped by and in many places formed entirely of the earlier gravel and clay deposits. These deposits are usually characterized by a dull-red color, due to the more complete oxidation of their constituents, this oxidation being due in turn to the fact that the red clays are older and have been exposed longer to weathering than the gray gravels and sands of the modern stream washes. These older benches usually slope steeply toward the south, and their lower margins are as a rule buried under the modern wash and are indistinguishable from it; but in some localities, as east of Eaton Wash, north of Duarte,

and on either side of upper San Dimas Wash, the limit of the older alluvium is marked by an abrupt escarpment. In addition to these exposures of the red wash along the terraces at the foot of the mountains, a few low knobs of this older material lie out in the plains, projecting distinctly above the modern gray stream wash. The most conspicuous and best known of these occurrences are Indian Hill, north of Claremont, and the Red Hills, northeast of North Ontario.

The fact that this older formation occurs at so many points at a greater elevation than the later wash is evidence, although not proof, that mountain-making forces have been in operation since it was deposited, and that the San Gabriel Mountains are now higher than when it was laid down, and they hint that the correlative process—valley deepening—which so often accompanies mountain growth, has likewise been under way and has resulted in a deeper San Gabriel Valley than before.

Although this greater elevation is imperfect evidence of the continued activity of mountain-making forces, actual proof of such activity is found in one or two places, where the old alluvium has been very distinctly folded, and the attitude of its beds, originally horizontal, has been changed to vertical or nearly vertical. East of the mouth of Sawpit Canyon, in an exposure along the edge of the mesa, the red clays and gravels of the old alluvium are found nearly on edge, that is, they dip 60° or 70° S. away from the mountains; and at a number of points farther east lesser dips of 20° or 30° may be noted. These facts indicate that marked crustal movements have taken place since the deposition of the earliest alluvium. These are the movements which presumably have resulted in an increase in the height of the San Gabriel Range.

Although the modern alluvium, the gray wash which underlies the greater part of the San Gabriel Valley and the Cucamonga Plains, is the important water-bearing formation, the older wash is also of direct importance in many localities. Producing wells of value have been drilled in it in the vicinity of Laverne and San Dimas and along the northeastern slope of the Red Hills. It also has a most important indirect effect, in that an older topography—hills and valleys and plains of the older material—has been buried by the later gray wash or has been deeply cut into by the streams which have deposited it; and now these buried or partly buried old hills and valleys deflect or retard or otherwise modify the underground circulation through the later wash, which has been deposited in the older valleys and around the older hills.

These effects of the relations of the alluvium of the two periods are treated more in detail in the discussion of the ground-water conditions in each of the communities. But before this discussion is

taken up it is desired to outline, in a general account of the physical geography, the origin of the mountains and valleys and their relative ages. This is a matter of scientific rather than of practical interest, although in the operation of the forces which have given southern California her marvelous diversity of abrupt and rugged mountains and fertile plains, the deep, alluvium-filled basins which are now so important as underground reservoirs have come into being.

PHYSIOGRAPHY.

GENERAL FEATURES.

The corner of Kern, Los Angeles, and Ventura counties, Cal., lies just south of Tejon Pass and near the northern edge of that great mountain area in which the Sierra proper, the northern and the southern Coast ranges, and what may be regarded as the southern representatives of the Sierra, i. e., the San Gabriel and the San Bernardino mountain masses, merge. Southwest of this mountain nodal point lies the Pacific Ocean. Northeast of it is the Mohave Desert. Toward the north the great San Joaquin Valley opens and separates the Sierra from the Coast ranges. Toward the southeast lies the valley of southern California, in a general way comparable in its geographic relations to the San Joaquin Valley, but much smaller in area and very much more complex in character and origin.

This valley consists of a number of distinct basins which are separated by physical barriers so low or so interrupted by passes that they present no serious obstacle to intercommunication between the various cultivable lowlands; but the ranges north and east of these connected basins separate them completely from the northern valleys and from the deserts and give a logical basis for grouping them together as they are grouped in commercial, agricultural, and historical nomenclature, under the collective term "valley of southern California."

As with increasing settlement the necessity has arisen for local names by which the various subdivisions of the valley could be distinguished, these have been supplied, and, as is usually the case in human occupation, they are not merely commercially convenient designations, but have an apt geographic significance which renders them quite as available for the use of the scientific geographer as for the merchant, the tourist, or the traffic manager.

The more important of these subdivisions of the greater valley are the coastal plain, between the Puente Hills and the sea; the San Fernando Valley, an inclosed basin forming the extreme northwestern lobe of the greater lowland; the San Gabriel Valley, another basin inclosed on the east, west, and south by diverging arms of the Coast Range, and abruptly limited on the north by the southern face of

the San Gabriel Mountains; the Cucamonga Plains, east of the San Gabriel Basin and passing without intervening physical barriers into the San Bernardino Valley, itself the northeasternmost of the local basins; and finally the San Jacinto Valley, an irregular area drained by San Jacinto River and made up of a multitude of local valleys and intervening irregular heights.

ORIGIN OF PHYSICAL FEATURES.

In the geographic and physiographic sense this valley and its surrounding heights constitute one of the most complex areas of the State. California mountains generally seem to be the immediate products of crustal movement. Many individual ranges are to be explained as results of local uplift. In the interior of the continent and along its eastern margin heights of this character are more uncommon. There it is usual to find that individual mountain groups result from differential erosion acting on broad heights like the Appalachian plateau. In the Pacific coast region, on the contrary, mountain masses of erosional origin are unusual; the individual uplift is the rule.

As this type of mountain range is well marked and to be recognized at many places along the Pacific coast, so there is a corresponding type of valley very common here and in the adjacent deserts, less usual elsewhere, and well illustrated by the individual basins which together constitute the valley of southern California. This is the constructional basin, due, like the mountain ranges, to crustal movement instead of to erosive action. Normally the world over, valleys are due to running water—the greater valleys to long-continued erosion or to erosion of soft rocks, the minor valleys to erosive action of short duration or acting on resistant rocks. It is perhaps even less usual to find lowlands that are directly due to crustal movement than to find mountain ranges of this character, but in southern California all the important lowlands, as well as the uplands, are direct results of crustal deformation. Only the details of sculpturing—the form of the individual peaks and ridges, the canyons, the grade of the mountain streams, and the slopes of the mountain sides—are due to the subaerial erosive agents, water, ice, and wind; the mountain mass as a whole is an upthrust block of the earth's crust. Similarly, the details of the surface of the broader lowlands are due to erosive agents. Their action here, however, has been just the reverse of that in the mountain areas. There the effect of these agents has been to reduce the heights, to undo the work of the mountain-making forces. In the valleys they have deposited the materials which have been removed from the uplands, filled the

original depressions, and covered the irregularities in their surfaces; in a word, they are leveling agents, and if their action were not counteracted by that of the mountain-building forces, the whole surface would eventually be reduced to a plain.

The details of the movements in which southern California's attractive alternation of valley and plain originated will perhaps never be known. Many more of them than are now available will, however, be worked out in the detailed geologic and physiographic investigations of the future. But it is possible even with our present imperfect knowledge to outline in a broad way what has happened.

In the middle and northern Sierra, where close geologic studies have been completed, it has been determined that late in Tertiary time the area occupied by the present Sierra Nevada was one of comparatively low relief, with gentle slopes and streams of moderate grade, and that the major part of the movement which has resulted in the present great range has taken place since. It is probable that the history of southern California corresponds in its broad outlines with that of the northern part of the State, and that here, until late in the Tertiary, the mountain ranges were much lower than they are now and the valleys much less deep. It is clear that the forces which have produced these mountains and valleys began to act before the close of the Tertiary period, because the latest Pliocene deposits contain gravels, widely distributed and in many places coarse. Their coarseness indicates that mountains existed near by at the time they were laid down, and their relation to the Tertiary beds whose deposition just preceded theirs indicates that the earlier beds were disturbed between the two epochs. The present mountains and valleys began to form toward the end of the Tertiary, and it is likely that they have been in process of formation ever since. In fact, it seems probable that mountain-making forces are as active on this part of the Pacific coast at present as they have been at any time since early earth history. Incidents like the Owens Valley earthquake of 1872, the San Jacinto earthquake of 1900, the great San Francisco disaster of 1906, and the innumerable minor temblors which occur from time to time are evidences of the activity of these forces. Science no longer regards it as probable that mountains originate in a night, in one tremendous cataclysm, except in volcanic regions. Ordinarily their growth is a gradual process. There are movements of a few inches, or at most of a few feet, from time to time, and the cumulative results give us mountains thousands of feet high and basins thousands of feet deep, where originally were only broad plains.

FAULT LINES.

Movements such as those just discussed, by which the highlands and lowlands are differentiated, are concentrated along lines of weakness where the crust yielded to the earliest strains. When such lines of weakness are once established, they tend to perpetuate themselves as the crust adjusts itself to later strains by yielding along the same lines. These lines of yielding are either faults—actual fractures of the crust—or flexures.

About the borders of the valley of southern California are a number of clearly defined fault lines of this character, movement along which has evidently played a commanding part in the development of the present physical features. The dominant fault of the entire region is the great fracture which extends northwest and southeast along the south base of the San Bernardino Mountains and the north base of the San Gabriel Mountains, and is a continuation of the fault readjustment along which proved so destructive to the country about San Francisco Bay on April 18, 1906. Another disturbance which for at least a part of its length is a fault line is of importance to the oil men of California, because many of the producing wells of this part of the State are found along it. It limits the Santa Ana Mountains on the northeast as far as the lower canyon of Santa Ana River, where it crosses the range and extends along the Puente Hills, near their southern edge, to the vicinity of Whittier, and perhaps farther. A third fracture of this character lies north of San Jacinto and skirts the south base of the badlands which separate the Alessandro Valley from San Timoteo Canyon. Another, somewhat less regular than those described and believed to be older in the sense that no movements have taken place along it as recently as along some at least of the others, bounds the San Gabriel Mountain mass on the south and separates it from the cultivated lowlands of the foothill belt.

It is to be understood clearly that crustal movements along these axial lines—those in an upward direction producing mountain masses, those in a downward direction resulting in basins and valleys—were probably in all cases accompanied by twisting and distortion of the surfaces thus uplifted or depressed, so that after the movement had been accomplished these surfaces were no longer approximately plane, as they probably were when the movements began. Hence the mountain tops, even before the erosion inaugurated by the uplift had destroyed the original surfaces, were probably not level, although they must have included many nearly level areas, and the basin bottoms were likewise depressed much more at one place than another, and so were very irregular.

RELATIVE AGES OF THE PHYSICAL FEATURES.

All the mountains and valleys of southern California have come into being very recently, in a geologic sense, but not all are of the same age. In a great many cases evidence either does not exist or has not been brought out to determine which of two features is the older; but in the case of the two mountain groups, the San Gabriel and the San Bernardino, the dominating mountain masses of this region, evidence apparently does exist for deciding this highly interesting question. This evidence is largely physiographic—that is, it lies in the character of the land forms and so is of a very delicate nature.

If from some commanding point like the summit of Santiago Peak, in the Santa Ana Mountains, the two neighboring ranges, the San Gabriel and the San Bernardino groups, are carefully examined, striking differences in their physical aspect at once become apparent. One seeks in vain for horizontal lines along the San Gabriel tops; a confusion of peaks and ridges of discordant and seemingly unrelated heights makes up the mountain mass. The San Bernardino range is in striking contrast with this. Its west end especially displays a long even sky line at elevations between 5,000 and 6,000 feet above the sea. On the east the broad masses of San Gorgonio Peak rise much higher.

If one enters these ranges to explore them in detail, corresponding differences are found. The San Gabriel Mountains present a labyrinth of canyons and ridges and peaks, with no level areas of any size. The ridges have narrow summits; the peaks are sharp; the streams are all evenly graded from source to mouth. In the San Bernardino Mountains, on the contrary, there are many wide upland valleys, forested and grassy glades, and lakes or playas like Bear Lake and Baldwin Lake. Where these upland levels are attained it is difficult to realize that one is actually in the high mountains. The surrounding topographic forms are rounded and gentle, the level areas are extensive, the streams meander placidly through broad meadows, and the topographic type is that of a rolling country of moderate elevation. But as the edge of these interior uplands is approached the streams plunge into precipitous canyons, the slopes are as steep as earth and rock can stand, the roads and trails twist and turn and double to find a devious and precarious way to the valleys below.

These topographic differences—the presence of broad uplands in one range and their complete absence in the other—have a definite meaning in the history of the mountain masses. The smooth forms are conceived to have been produced by long-continued erosion at relatively low levels in accordance with well-established principles, and their preservation since the mountain mass has been elevated is due to the short time that has elapsed since that event. With the further passage of time, the canyons that are now so pronounced a

feature of the border of the San Bernardino mass will have extended to its very heart, and the smooth uplands that now occupy the center of the range will have disappeared. The San Bernardino Mountains will then be as the San Gabriel Mountains are now, a thoroughly dissected range. The important fact that they are not at present in this condition is regarded as satisfactory evidence that they are much younger—that is, that a much shorter time has elapsed since the elevation of the San Bernardino block into a mountain range than since the similar elevation of the San Gabriel block.

SUMMARY.

The topography of southern California in its broad features, and of the foothill belt in particular, is due to the latest crustal movements. These movements may have produced folding in rock masses, but their distinctive effect has been to originate the present relief of the country, to raise the mountains here and to depress the valleys there, the uplands and the lowlands being separated by zones of sharp flexure or of faulting.

Finally, the details of the present topography have been carved by erosion since the differential movement began. Crustal readjustments in response to internal strain, then, have produced the mountain masses and deep valleys, while contemporary and later erosion has produced the canyons and the details of mountain slopes, and has leveled the original basins into broad plains by spreading over them the material removed in sculpturing the mountain areas.

The different mountain masses, although all are comparatively recent, have not been uplifted at the same time. The San Gabriel Range is in this sense much older than the San Bernardino Range, which has come into existence as a mountain mass at a distinctly later date than its neighbor.

RAINFALL.

DISTRIBUTION AND AMOUNT.

The annual distribution of rainfall within the foothill belt is like that throughout the Pacific slope of southern California, since the entire region is one meteorological province with characteristics common to all parts. The chief of these characteristics is the division of the year into wet and dry seasons, the former including the months from November to April, and the latter the remainder of the year. The driest months are June, July, August, and September, during which practically no rain falls, and the wettest are December, January, February, and March, while April and May in the spring and October and November in the autumn serve to bridge the interval between the more pronounced seasons, a variable but generally slight rainfall being recorded for these months.

The geographic distribution of the rainfall within the province is quite as definite as its distribution in time. During the winter season, when the winds from the Pacific pass from the relatively warm ocean over the cooler land, they acquire its temperature, lose capacity to retain moisture, and drop a part of their burden as rainfall. Other things being equal, the greater the reduction in temperature they suffer the greater the rainfall; hence the mountain areas surrounding the southern California lowlands, being higher and cooler, receive heavier rains, and the communities nearer the mountains receive more than those at a greater distance from them. Thus the average at Anaheim is about 12 inches, and at Riverside about 11, while at Los Angeles and San Bernardino, nearer the mountains, the precipitation is between 15 and 16 inches.

This increase from the outlying plains toward the base of the mountains is known to be maintained as the higher parts of the mountains are approached, but exact data to illustrate this generally known fact are not available for the foothill belt, no stations being regularly maintained in the adjacent mountains.

The general character of the rainfall for the valley is illustrated by the following precipitation tables:

Rainfall, in inches, at Los Angeles, Cal.

Year.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1877–78	0.00	0.00	0.00	0.86	0.45	3.93	3.33	7.68	2.57	1.71	0.66	0.07	21.26
1878–79	.00	Tr.	.00	.14	Tr.	4.70	3.59	.97	.49	1.19	.24	.03	11.35
1879–80	.00	.00	.00	.93	3.44	6.53	1.33	1.56	1.45	5.06	.04	.00	20.34
1880–81	Tr.	Tr.	.00	.14	.67	8.40	1.43	.36	1.66	.46	.01	.00	13.13
1881–82	.00	Tr.	Tr.	.82	.27	.52	1.01	2.66	2.66	1.83	.63	Tr.	10.40
1882–83	.00	.00	Tr.	.05	1.82	.08	1.62	3.47	2.87	.15	2.02	.03	12.11
1883–84	Tr.	.00	.00	1.42	.00	2.56	3.15	13.37	12.36	3.54	.34	1.39	38.13
1884–85	Tr.	Tr.	Tr.	.30	1.06	4.64	1.05	Tr.	.01	2.00	.06	Tr.	9.12
1885–86	Tr.	Tr.	Tr.	.26	5.52	1.63	7.72	1.38	2.50	3.29	.00	.01	22.31
1886–87	.24	.21	.00	.01	1.18	.18	.20	9.25	.24	2.30	.20	.04	14.05
1887–88	.07	.00	.15	.12	.78	2.67	6.03	.77	3.15	.11	.02	Tr.	13.87
1888–89	.03	.08	Tr.	.36	4.01	6.26	.25	.92	6.48	.27	.62	.00	19.28
1889–90	.00	.61	.00	6.95	1.35	15.80	7.83	1.36	.66	.22	.03	.02	34.83
1890–91	.00	.03	.06	.03	.13	2.32	.25	8.56	.41	.26	.31	.00	12.36
1891–92	Tr.	.00	.06	.00	.00	1.99	.88	3.19	3.39	.22	2.06	.06	11.85
1892–93	.00	.01	.00	.33	4.40	4.18	6.29	2.27	8.52	.19	.06	.03	26.28
1893–94	.00	.00	Tr.	.75	.20	3.65	.94	.49	.37	.13	.20	Tr.	6.73
1894–95	Tr.	.01	.73	.02	.00	4.62	5.84	.46	3.77	.46	.19	.01	16.11
1895–96	Tr.	Tr.	Tr.	.24	.80	.78	3.23	Tr.	2.97	.19	.30	Tr.	8.51
1896–97	.02	.01	Tr.	1.30	1.66	2.12	3.70	5.62	2.31	.02	.10	Tr.	16.86
1897–98	Tr.	.00	.00	2.47	.01	.05	1.26	.51	.98	.03	1.75	Tr.	7.06
1898–99	.07	Tr.	.02	.09	Tr.	.12	2.64	.04	1.81	.18	.04	.58	5.59
1899–1900	.00	.01	Tr.	1.59	.90	.90	1.17	Tr.	.99	.54	1.81	Tr.	7.91
1900–1901	Tr.	Tr.	Tr.	.26	6.53	Tr.	2.49	4.38	.45	.68	1.50	Tr.	16.29
1901–2	Tr.	.09	.03	1.88	.46	Tr.	1.62	3.35	2.98	.16	.03	Tr.	10.60
1902–3	Tr.	Tr.	Tr.	.40	2.08	2.50	2.10	1.52	6.93	3.77	Tr.	.02	19.32
1903–4	.00	Tr.	.43	Tr.	.00	Tr.	.14	2.68	4.50	.97	Tr.	Tr.	8.72
1904–5	Tr.	.17	.28	.69	.00	2.45	2.57	6.06	6.00	.35	.95	.00	19.52
1905–6	.00	.00	Tr.	.08	2.98	.20	3.85	2.47	7.35	.69	1.02	.01	18.65

Average, twenty-nine seasons, 15.60 inches.

Rainfall, in inches, at Pasadena, Cal.

Year.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1883–84	0.00	0.00	0.00	1.30	0.00	2.73	6.10	13.21	12.99	5.93	0.77	1.90	44.93
1884–85	.00	.20	.00	.25	.89	2.95	1.22	.00	.05	3.00	.33	.11	10.00
1885–86	.00	.14	.00	.00	7.49	2.05	7.40	2.32	2.45	4.11	.15	.00	26.11
1886–87	.05	.76	.04	.10	1.15	.17	.10	10.05	.27	2.33	.28	.00	15.50
1887–88	.17	.00	.53	.12	1.12	4.98	7.40	1.57	5.62	.46	.00	.00	21.77
1888–89	.00	.00	.00	.45	5.08	6.71	.09	1.08	8.83	.41	.95	.00	24.20
1889–90	.00	.62	.00	9.31	1.45	17.17	7.92	2.66	.90	.60	.20	.06	40.89
1890–91	.00	.00	.26	.07	.35	3.52	.14	10.75	.08	1.84	.73	.00	18.34
1891–92	.00	.00	.09	.00	.05	2.25	1.54	3.40	4.23	.25	3.94	.00	15.75
1892–93	.00	.00	.00	.62	3.72	4.30	5.65	2.07	9.84	.47	.00	.00	28.67
1893–94	.70	.00	.00	.80	.20	4.77	1.51	.82	.96	.13	.61	.00	10.59
1894–95	.00	.00	.85	.04	.00	7.24	8.10	1.44	4.53	.53	.25	.00	23.07
1895–96	.00	.00	.00	.32	1.30	.91	2.96	.00	3.73	.50	.17	.00	9.89
1896–97	.05	.15	.00	2.04	1.88	2.33	5.94	5.34	3.57	.00	.23	.00	21.53
1897–98	.05	.15	.23	2.40	.10	.26	1.50	.69	1.14	.39	1.98	.03	8.92
1898–99	.01	.00	.27	.49	.52	.64	3.18	.00	2.08	.12	1.88	.00	9.19
1899–1900	.00	.00	.00	2.02	1.43	1.62	1.11	.00	1.55	.82	2.42	.00	10.97
1900–1901	.00	.00	.05	.34	9.80	.00	3.78	6.80	.17	1.16	1.62	.00	24.22
1901–2	.00	.00	.00	2.76	.73	.00	1.63	3.01	3.29	.38	.09	.00	11.89
1902–3	.00	.00	.00	.53	3.24	3.07	4.03	.90	9.70	3.09	.00	.00	24.56
1903–4	.00	.00	.34	.00	.00	.00	.21	3.89	4.81	.93	.01	.00	10.19
1904–5	.00	.53	.34	.96	.00	1.90	2.03	10.44	8.65	.18	1.44	.00	27.07
1905–6	.00	.00	.05	.17	2.55	.17	4.44	2.54	10.83	2.64	1.67	.00	25.06

Average, twenty-three seasons, 20.14 inches.

Rainfall, in inches, at Pomona, Cal.

Year.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1886–87	0.00	0.00	0.00	0.00	1.05	1.25	0.20	8.28	0.00	2.27	0.28	0.00	13.33
1887–88	.00	.00	.00	.37	1.25	3.56	8.33	1.70	6.63	.00	.00	.00	21.84
1888–89	.00	.00	.00	.00	4.70	6.04	.17	1.48	9.32	.87	.77	.00	23.35
1889–90	.00	.00	.00	3.85	1.82	12.59	7.10	2.56	.52	.31	.00	.00	28.75
1890–91	.00	.14	1.11	.05	.45	3.35	.13	12.78	1.16	1.67	1.02	.00	21.86
1891–92	.00	.12	.11	.00	.00	2.69	1.02	3.41	2.84	.23	3.86	.42	14.70
1892–93	.00	.00	.00	.02	3.45	2.92	7.06	3.87	10.85	.64	.22	.05	29.08
1893–94	.07	.00	.17	1.84	1.44	4.59	1.81	1.13	.95	.26	.44	.00	12.70
1894–95	.00	.00	.63	.02	.00	8.66	9.12	2.43	4.44	1.00	.38	.00	26.68
1895–96	.00	.00	.00	.05	1.36	.91	2.90	.00	4.69	.21	.03	.00	10.15
1896–97	.05	.24	.00	2.44	1.49	1.69	5.20	6.92	4.41	.00	.43	.00	22.87
1897–98	.00	.00	.25	2.84	.53	1.04	2.16	.74	1.46	.13	2.03	.00	11.18
1898–99	.00	.00	.06	.07	.06	.44	2.83	.31	2.97	.07	.07	.89	7.77
1899–1900	.00	.00	.30	1.90	1.94	1.04	1.74	.13	1.35	.80	2.60	.00	14.80
1900–1901	.00	.00	.00	.44	10.12	.00	4.22	4.81	.51	.41	1.47	.01	21.99
1901–2	.00	.00	.17	1.95	.72	.03	2.41	3.21	4.21	.46	.19	.10	13.45
1902–3	.00	.00	.00	.47	1.62	2.91	1.57	1.77	7.23	4.19	.15	.01	19.92
1903–4	.00	.02	.38	.01	.00	.01	.33	2.68	5.57	1.24	.07	.00	10.31
1904–5	.00	.23	.00	1.19	.00	1.42	3.36	8.05	8.50	1.35	2.34	.01	26.45
1905–6	.00	.00	.02	.12	2.71	.64	4.81	2.50	9.65	1.58	1.31	.41	23.75

Average, twenty seasons, 18.60 inches.

Rainfall, in inches, at San Bernardino, Cal.

Year.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1870–71	0.00	0.00	0.02	0.09	3.11	0.89	6.91	2.21	0.19	0.34	0.11	0.07	13.94
1871–72	.00	.04	.13	.60	.88	3.91	.00	2.20	.37	.79	.06	.00	8.98
1872–73	.00	.18	.04	.00	1.17	4.40	6.50	1.25	.51	.84	.21	.00	15.10
1873–74	.00	1.06	.02	.01	.74	5.73	5.51	8.76	1.08	.48	.42	.00	23.81
1874–75	.00	.00	.06	1.82	1.88	2.20	7.20	.15	.22	.07	.05	.00	13.65
1875–76	.00	.00	.00	.00	7.50	.02	6.55	1.92	3.41	.44	.03	.03	19.90
1876–77	.00	.00	.00	.20	.40	.00	3.50	4.03	.83	.26	.30	.00	9.52
1877–78	.00	.00	.00	.86	.50	3.95	3.33	6.68	2.57	1.71	.66	.07	20.33
1878–79	.07	.00	.02	.14	.05	4.70	3.59	1.00	.50	1.20	.24	.03	11.54
1879–80	.11	.02	.01	.94	3.40	6.50	1.56	1.33	1.45	5.00	.04	.00	20.36
1880–81	.00	.00	.00	.14	.67	8.80	1.40	.36	1.66	.46	.01	.00	13.50
1881–82	.00	.00	.00	.80	.27	.50	1.11	2.65	3.30	2.91	.00	.00	11.54
1882–83	.00	.00	.00	.10	.15	.45	1.60	1.10	2.82	2.95	.00	.00	9.17
1883–84	.19	.00	.53	.85	.09	2.63	1.63	12.20	9.95	5.68	3.17	.59	37.51
1884–85	.00	.00	.00	.00	.11	3.75	2.79	.11	.28	1.89	1.69	.19	10.81
1885–86	.00	.00	.00	.39	4.36	1.20	6.34	2.52	4.18	2.36	.32	.16	21.83
1886–87	.00	.00	.00	.00	.11	.61	.39	6.44	4.41	1.90	.42	.22	14.50
1887–88	.11	.04	.09	1.17	2.29	1.91	4.01	3.60	3.41	.58	.52	.03	17.76
1888–89	.00	.00	.00	.05	4.12	4.64	.93	1.50	6.55	2.05	1.13	.00	20.97
1889–90	.17	.63	11	2.30	2.23	10.85	5.44	2.52	.89	.00	.31	.00	25.45
1890–91	.13	2.16	.88	.58	1.27	3.02	.00	7.78	.06	.53	1.67	.00	18.08
1891–92	.00	.91	.93	Tr.	Tr.	1.67	3.24	3.30	1.75	.37	2.10	.08	14.35
1892–93	.00	.00	.00	.16	1.02	2.23	4.53	3.37	8.00	.48	.03	.00	19.82
1893–94	.20	.00	.05	1.05	.30	2.28	1.26	.88	1.15	.40	.56	.00	8.13
1894–95	.00	.16	.37	.15	.00	7.25	7.39	1.14	3.44	.64	.44	.00	20.98
1895–96	.00	.00	.00	.00	1.14	.66	2.02	.00	2.92	.37	1.00	.00	8.11
1896–97	Tr.	.17	.00	2.10	.98	1.09	3.40	5.40	3.41	.08	.11	.00	16.74
1897–98	Tr.	.00	.13	2.10	.21	.57	2.10	.60	.97	.48	1.08	.00	8.24
1898–99	.00	.00	.00	.03	.05	.44	2.03	.51	3.22	.07	.19	.95	7.49
1899–1900	.00	Tr.	.01	.81	1.47	.84	.92	.00	.92	1.96	1.71	.09	8.64
1900–1901	.34	.00	.23	.36	6.10	.00	3.48	4.58	.43	.56	1.23	.05	17.36
1901–2	.00	.27	.07	1.09	.28	.04	1.65	3.02	3.89	.57	.12	.15	11.15
1902–3	.01	.00	.00	.09	1.94	1.94	1.96	1.67	6.47	3.10	.24	.00	17.42
1903–4	.00	.15	.46	.07	.00	.00	.18	2.21	5.34	.80	.16	.00	9.37
1904–5	.00	.14	.06	.32	.00	1.03	3.92	6.58	6.00	1.18	1.55	.00	20.78
1905–6	.00	.00	.13	.00	2.81	.74	2.97	2.89	8.00	1.16	.96	.22	19.88

Average, thirty-six seasons, 15.74 inches.

The San Bernardino and Los Angeles records are the longest in this part of the State, and therefore give the most reliable general averages; but since Los Angeles is near the southern edge of the foothill area, and San Bernardino about an equal distance from the mountains, these records probably express about the lowest rainfall within the district under consideration. The record at Pasadena, kept by Mr. Nelmes, covers a period of twenty-three seasons, during which the average precipitation was 20.14 inches. This average is probably somewhat higher than the final average will prove to be when that shall have been determined by longer records. This conclusion is reached from an inspection of the records at Los Angeles and San Bernardino, where the average for the last twenty-three seasons is in each case slightly greater than the average for the full period of observations. Similar reasoning indicates that the twenty-year average of 18.60 inches, now available for Pomona, is slightly below the final average which will be found for this point. Both Pasadena and Pomona, however, have heavier rainfall than Los Angeles and San Bernardino, since they lie nearer the base of the mountains; and were records available from points on the slopes and at or near the summits they would show still heavier rainfall, in accordance with the well-established fact of a progressive increase of precipitation from the mountain bases to a point near their summits.

DEPENDENCE OF WATER SUPPLIES ON RAINFALL.

The significance of the annual rainfall to the irrigating communities lies in the direct and immediate dependence on it of the surface run-off from each of the mountain drainage basins and in the less immediate but not less important or final dependence of the underground reservoirs on it for recharge.

The marked contrast between the summer and winter run-off from the mountain canyons, with its unfavorable effect on irrigation possibilities and on the recharge of subterranean reservoirs, is of course due primarily to the division of the year into two seasons, a wet and a dry, with strongly contrasted precipitation; but other factors also exert a pronounced influence, and it so happens that nearly all of them in southern California are unfavorable to uniformity of flow. Among these factors are the length and character of drainage lines, the steepness of slopes and of stream channels, the character of the rocks in a drainage basin, and the condition of the forest and brush cover over the slopes.

Where drainage lines are short and direct and channels are straight instead of tortuous, a minimum of time is required for the passage of a given flood wave from the headwaters of the stream to its mouth, and so there is but a limited opportunity for the absorption of water by porous rocks and débris to be released later as summer flow.

A closely related factor is that of steep slopes and stream channels. The process of absorption of water by soil and rocks is a slow one and is controlled by the rate of percolation through the soil, away from the saturated surface, and by the length of the period of saturation. From steep slopes and stream channels of high gradient the water escapes quickly, so there is but little opportunity for its absorption. The streams of the San Gabriel Mountains that drain into the foothill belt have relatively short and direct courses, and the slopes in this mountain range and the grades of the streams are especially steep. These conditions result in extremely rapid run-off in heavy floods of very short duration.

The influence exerted by the type of rock in a drainage basin is also most marked in its effect on the character of the run-off. Loose sandstones absorb water like sponges, to yield it slowly at some lower point, perhaps in a distant drainage basin. Cavernous limestones may offer tortuous underground passages through which water escapes slowly. But dense granitic and metamorphic rocks have little absorptive or storage capacity unless they are extensively shattered, and such water as falls upon them is usually shed promptly. By far the greater part of the San Gabriel Range is made up of rocks of these nonabsorptive types.

Finally, the various cover growths are of great importance in modifying run-off. Trees and brush act in many ways to this end.

They hold loose fragments of rock by their binding root systems, so that they are not carried down to the stream channels so soon. The crevices about the rock fragments which are thus held become little storage reservoirs. The trees also aid in making these crevices by the prying action of their roots and by the disintegrating action of the vegetable acids which are yielded by their decay. The various growths build up a porous absorptive soil by the litter which they shed and the rock sand which becomes enmeshed in their roots, and they protect the soil which thus accumulates and prevent it from being swept away. Finally, they interfere directly with run-off by the obstacles which their roots, stems, and fallen leaves and branches offer to the flow of water over the surface. In all of these functions the immediate escape of rains as sudden floods is checked, and their absorption to be slowly released later is encouraged. The effect of forest and brush cover, then, is to decrease the violence of winter floods and to maintain the stream flow during the crucial summer irrigating season. Forest cover throughout the San Gabriel Mountains is in bad condition through the recurrence of destructive fires during past centuries. Systematic efforts are now being made by the United States Forest Service and by the State forester to improve these conditions by preserving from further destruction such covered areas as remain and by extending timber growth through tree planting. These efforts are for the benefit of the southern California communities which depend on the water supply from the mountains, and are deserving of their heartiest support and most earnest cooperation.

The statement has frequently been made that the underground waters are just as dependent as the surface run-off on precipitation within the local contributing drainage basins, but the tenacity of the oft-asserted belief that these subterranean reservoirs have some other source than local rainfall makes it desirable to repeat this statement with emphasis. Each of the important subterranean basins in southern California is supplied exclusively by the water which falls upon its surface or flows into it through some tributary stream. Any other hypothesis, as, for example, that waters from the distant Sierra or Colorado River or Pacific Ocean may, by underground channels or by seepage, reach the San Gabriel Valley or the Pomona neighborhood, is erroneous, and conclusions based on it are wrong and lead to a false policy in the utilization of the ground waters.

The permanence of the underground reservoirs as sources of water supply is dependent on all the conditions which have been outlined as affecting surface run-off, because, as just stated, it is the surface run-off from the mountain areas which must be relied on to recharge these reservoirs; and, in addition, whatever makes this surface run-off erratic—extremely high in winter and extremely low in summer—not only makes it less effective in the recharge of the underground

basins, but increases the summer drafts on them. A discouragingly large proportion of the greater floods escapes entirely to the sea. These floods can not be used by the surface systems, and they pass over the gravels of the valleys too rapidly and in too great volume to be fully absorbed, and so are largely wasted. It is obvious that whatever will reduce the violence of floods will lessen the total loss of waters by surface flow to the sea and will make more effective the restoration of ground-water levels.

These levels suffer in still another way at the present stage of development of the country, by the concentration of the run-off in the winter months and its reduction to a low point during the irrigating season. Since the discovery in the nineties that large bodies of ground water were available for irrigation, there has been a constant tendency to extend acreage beyond the amount which can be covered by the summer surface run-off and to make up the deficiency during that period by pumping. When the summer flow is especially low and continues low for a long period, the pumping season is greatly extended and the drafts on the underground basins are proportionately increased.

To sum up: The available quantity of ground waters is adversely affected by whatever tends to make surface flow more erratic. This effect is brought about in two ways—first, by the large proportion of waters which escape wholly when winter floods are violent; and second, by the greater drafts on underground sources made necessary when summer run-off is low.

STORAGE FACILITIES.

The canyons in the San Gabriel mountain range are too narrow and too steep for storage sites, except of very inferior capacity and excessively high unit cost, and the run-off is so erratic that to be effective reservoirs must be of exceptional capacity. The recorded flows of San Gabriel River vary between a minimum of 3 second-feet and a maximum of 11,130 second-feet; and the total estimated annual discharge since systematic records have been kept varies from a minimum of 10,489 acre-feet to a maximum of 164,700 acre-feet. These minima are probably nearly absolute, since they were obtained during the seasons of lowest rainfall known in southern California; but greater maxima than those given were undoubtedly reached during the season of 1883-84, when the precipitation was nearly twice that of any winter since the stream flow has been accurately measured.

With such widely varying annual run-off, reservoirs capable of storing enough water to supply the tributary lands during two seasons, at least, would be required for safety. Such reservoir sites do not exist in the San Gabriel Mountains.

MEASURES FOR CONSERVATION OF WATERS.

In the lack of surface reservoirs, such minor helpful measures as are possible must be taken to prevent the present distressing waste of flood waters. Restoration of forest and brush cover is one of the most effective of these, although it accomplishes results but slowly. Gradually through reforestation summer flow should be increased and the volume and suddenness of winter floods somewhat lessened. Another measure which is practiced in a small way is the spreading of flood waters over the sand and gravel areas about the canyon mouths, so that they may be more fully absorbed and thus may increase the ground-water supply.

With certain important modifications, the simple principle that the quantity of water absorbed varies with the area of the flooded surface and with the time that it is covered is the basis of this work. If the character of a given flood channel can be so altered that the water in its escape covers twice the normal area, the amount absorbed will be increased twofold; and if the flow can be checked so that twice the normal time is required for the passage of the water between two points, absorption is again increased twofold. These are general terms, of course, and would be strictly true only if the flood waters were clear and if drainage from the flood channel were so free that the water could always escape as fast as it is absorbed. Neither of these conditions holds. Early flood waters are filled with fine suspended matter which is deposited as the water seeps into the river bed, and which soon forms a coating of but slightly permeable slime that tends to prevent absorption. Toward the end of a flood stage, when the water is clear, this slime is washed away and absorption becomes more effective.

In those parts of the flood-water channel which lie at some distance from the base of the mountains, where the ground-water plane is near the surface, rapid absorption in the stream channel quickly raises the ground-water plane locally, so that the stream is then flowing, as it were, upon a saturation ridge, and further absorption can take place only as rapidly as the waters can percolate away from this ridge. The practical result of this principle is that the first part of a flood is more effectively absorbed than the latter part, and the first floods at the beginning of a rainy season are more effectively absorbed than those which come later in the winter.

These are important practical modifications of the rule that absorption varies with absorptive area and time. In the application of this rule, flood waters are distributed over as large areas as possible near the heads of the alluvial fans, and the rate of their flow is checked as much as possible. The most effective work of this character that has been done thus far in southern California is that by the Riverside companies in Santa Ana Wash above San Bernardino. Here for

some years minor floods have been checked by temporary dams, and the water has been distributed in a small way over the sands of the river wash, with what the engineers in charge regard as excellent results. Similar work on a less extensive scale has been done by the Ontario companies on the Cucamonga fan and in the lower canyon of San Antonio Creek. The great difficulty in work of this kind is to unite the interests to be benefited, so that they will support a work whose results are not easy to demonstrate. But as water becomes more valuable in southern California, and as the direct dependence of the underground reservoirs on recharge during the rainy season becomes more clearly understood, it will be less difficult to unite these interests in a concerted movement to aid in the necessary engineering work.

ABSORPTIVE CAPACITY OF SANDS.

The absorptive capacity of the sands and gravels of varying coarseness in the different portions of an alluvial fan is a subject of debate, and the general opinion among engineers seems to be that absorption takes place most effectively and readily in the sands which occur in the lower part of the stream channel. When the size of the soil particles remains uniform, the transmission capacity of a mass increases with the square of the diameter of the individual particles. The size of the pores, although not the percentage of the open space, increases, and the effect of friction is greatly reduced with this increase. Percolation thus approaches flow as the sand or soil particles become larger and larger. In nature, however, sands rarely consist of particles of uniform size. They are usually heterogeneous mixtures, and their transmission capacity can be determined only by measurement. The effect of mixing particles of a larger size with a uniform sand is thus summarized by Slichter:[a]

> If to a mass of nearly uniform sand particles larger particles be added, the effect on the resistance to the flow of water will be one of two kinds, depending principally upon the ratio which the size of the particles added bears to the average size of the grains in the original sand. If the particles added are only slightly larger than the original sand grains, the effect is to increase the capacity of the sand to transmit water, and the more particles of this kind that are added the greater will be the increase in this capacity. . . . If, however, large particles are added, the effect is the reverse. If particles seven to ten times the diameter of the original sand grains be added, each of the new particles tends to block the course of the water. Thus, for example, a large bowlder placed in a mass of fine sand will tend to block the passage of the water. As more and more of the large particles are added to a mass of uniform sand, the rate of flow of water through it will be decreased until the amount of the large particles equals about 30 per cent of the total mass. From this time on the adding of the large particles will increase the capacity of the whole to transmit water, until, if a very large quantity of the large particles be added, so that the original mass of fine particles becomes relatively negligible, the capacity to transmit will

[a] Slichter, C. S., Water-Sup. and Irr. Paper No. 140, U. S. Geol. Survey, 1905, pp. 10-11.

approach that of the mass of the large particles alone. These facts have an important bearing upon the capacity of gravels to furnish water to wells or to transmit water in the underflow of a river. The presence of large particles is not necessarily to be interpreted as indicating a high transmission capacity of the material, for this is indicated only when the large particles constitute a large fractional per cent of the total mass, as would be the case where the large particles equal 40 or 50 per cent of the whole.

In an earlier paper[a] Slichter gives an interesting table showing the rate of percolation through transmitting media of different sizes under fixed conditions. From this table the following is adapted. A uniform size of grain, a standard porosity of 32 per cent, and a temperature of 50° F. are assumed in each case.

Rate of percolation of water through different kinds of soil.

Kind of soil.	Diameter of soil grains.	Velocity with a gradient of 100 feet per mile.
	Inch.	*Feet per year.*
Silt	0.0012	12
Very fine sand	.0028	66
Fine sand	.006	304
Medium sand	.014	1,650
Coarse sand	.03	7,577
Fine gravel	.12	121,229

When the soils are of uniform grain, therefore, the rate of percolation increases as the square of the diameter of the soil particles and the amount of water transmitted increases in the same ratio. Coarse material is therefore very much more effective than fine as a transmitting medium, when the sizes are not mixed. In alluvial fans, however, there is always mingling of coarse and fine material, but the average and probably the effective size of grain is usually much greater at the head of a fan than near its margins, and the transmission capacity is therefore believed to be greater near the head. To take advantage of this condition, distribution of flood waters should be effected at as high a point on an alluvial fan as is practicable, because absorption will be much more rapid at such a point. In some places it may be that the rough, bowldery condition of the head of the fan and the steep grades which exist there will counteract the advantages, and as a practical measure it will be advisable to effect the distribution at a lower point; or bed rock may lie near the surface, as in the Mill Creek fan and perhaps that of the Santa Ana in San Bernardino Valley, practically preventing rapid absorption. Where such conditions exist it is of course necessary to build the distributing works at lower points. So far as is known, however, bed rock does not lie near enough to the surface under the fans of the foothill belt to have an unfavorable effect. Steep grades

[a] Slichter, C. S., Water-Sup. and Irr. Paper No. 67, U. S. Geol. Survey, 1902, p. 27.

and rough ground for constructing distributing canals are the only adverse elements to be considered here.

ABSORPTION ESTIMATES.

The rate and the total amount of the recharge of the subterranean basins through the absorption of flood waters are exceptionally difficult to determine, because accurate measurements of floods are almost impossible to make on account of the steep grades and the indefinite channels that exist across the alluvial fans. But few data are available on the subject, and while theoretical considerations give indications as to what is happening, they can not generally be supported by figures.

In southern California one set of absorption measurements was made on two minor floods in the spring of 1903 by W. B. Clapp,[a] hydrographer, of the United States Geological Survey, and while Mr. Clapp does not regard his measurements as satisfactory, because of the small force and the limited time at his disposal and the inherent difficulties of the work, they yet give certain concrete conceptions of what takes place during the flood periods.

During the twenty-four hours of April 26, 1903, San Gabriel, San Dimas, Dalton, Santa Anita, and Eaton canyons discharged 757 acre-feet of undiverted waters into the San Gabriel basin, 454 acre-feet of which passed the bridge at Elmonte and was lost, while the remainder, 303 acre-feet, was absorbed by the gravels and joined the body of underground waters in the basin. On May 23 of that year the same streams discharged 225 acre-feet of undiverted waters, and all of this except the small amount lost through evaporation was absorbed, none passing the Elmonte bridge. During the two periods of measurement water was being returned to the San Gabriel Valley underground reservoir at the rate of 153 and 113 cubic feet per second.

These measurements were not made during the period of highest water. A flood with a discharge of about 1,220 second-feet occurred on April 17, nine days before the first measurement, and the flow in the San Gabriel slowly diminished from that time until long after the date of the second measurement.

Inasmuch as no calculation has been made of the diverted water used in irrigation, which in the San Gabriel systems was from 20 to 70 second-feet throughout the year, and a part of which was absorbed and returned to the ground waters, nor of the greater absorption during the heavier floods, nor of the rainfall over the San Gabriel Valley, which sinks directly as it falls and does not appear as run-off, nor of the hundreds of minor unmeasured rills which enter the basin during storms, perhaps one or the other of the figures given above may be not far from the average annual rate of recharge. Some slight additional

[a] Hoyt, John C., Water-Sup. and Irr. Paper No. 100, U. S. Geol. Survey, 1904, pp. 339 et seq.

weight is given to this assumption from the fact that the San Gabriel flow at the time of the last measurement was 167 second-feet, which is not far from the annual mean of 148 second-feet for 1903.

In the Paso de Bartolo, San Gabriel Valley ground waters rise in springs at the rate of 65 to 85 second-feet during the irrigating season. In addition, a considerable amount of water must pass into the air from the moist lands above the pass, by evaporation. This is ground water which is brought to the surface by capillarity and there evaporated, wherever the ground-water plane lies within a few feet of the earth surface. In addition, a certain amount of ground water escapes through the Paso de Bartolo as underflow without reaching the surface at all. Slichter,[a] using rather meager data, has estimated the amount of this underflow at 92 second-feet. This, added to 75 second-feet assumed as a mean of the spring waters, gives 167 second-feet of escaping ground waters, without reckoning evaporation or waters pumped for irrigation. These escaping waters must be about equal to the average annual recharge. It seems likely, then, from this consideration of the broad probabilities in the case, that a recharge of the San Gabriel Valley underground reservoirs takes place at a rate equal to a continuous flow ranging between 100 and 200 second-feet, and that, of course, drainage is affected at an equal average rate.

CHARACTER AND CONDITION OF SUBTERRANEAN RESERVOIRS.

The origin of the great reservoirs which are now so extensively drawn on in irrigation has been discussed in general terms in the section on physiography (pp. 13–18), but a résumé is introduced here preliminary to a more minute treatment of water levels. These reservoirs are irregular rock basins, due to the warping of the earth's crust as a result of those stresses to which it is continually subject. The Pacific coast region of the United States has of late been especially affected by such stresses, and its mountains and valleys are to a great extent due to them. The great interior valley of San Joaquin and Sacramento rivers is the most impressive example of a deep and extensive basin formed in this way, and the Sierra Nevada east of it is equally impressive as an example of a mountain range whose origin is to be sought in crustal movement. Earth stresses in the vicinity of the valley of southern California clearly have been most complex, resulting structures are irregular, and the final product has been a number of distinct rock basins irregular in trend and outline, each of which is an underground reservoir more or less extensively drawn on for irrigating waters. Among the more important and best known of these basins are the San Bernardino Valley, the San Jacinto Valley, the Cucamonga Plains, the San

[a] Slichter, C. S., Water-Sup. and Irr. Paper No. 140, U. S. Geol. Survey, 1905, p. 54.

Gabriel Valley, the coastal plain, and the San Fernando Valley. All of these are distinct, each has its own water supply, and the ground waters of each are used for irrigation, either within the basin or on accessible lands outside it.

Each of these rock-floored and rock-rimmed reservoirs is filled with loose material, sand, gravel, or clay, which has been eroded from the mountains as they rose and carried by the streams to the basins as they sank. This filling has been distributed over the basins in a rather even way, so that the present surface of each of them is a plain, usually with a gentle slope away from the mountains, the source of the material.

THE GLACIAL HYPOTHESIS.

Inasmuch as there is a rather widely prevalent idea in southern California—an idea which has been frequently presented in suits at law—to the effect that these sands, clays, and gravels are glacial in origin, it is perhaps worth while to present here the facts which make such a hypothesis untenable.

Students of glaciated regions have come to recognize certain phenomena as characteristic of ice-molded areas. Some or all of these evidences are invariably present where ice in glacial form has covered a region. Their complete absence in southern California leads at once to the setting aside of this theory.

Extensive glaciation in mountain valleys molds them into U form, cuts cirques at their heads, scars their walls and bottoms with striæ, and leaves moraines along their slopes and out on the plains beyond the mountains where the ice streams ended. None of these evidences are found in the valleys of the San Gabriel Mountains.

Ice flowing over mountain uplands or relatively smooth rock-floored plains shears off all rock protuberances, polishes the projecting surfaces into roches moutonnées, sweeps away rock-disintegration products, gouges out basins, which may later become lakes, and leaves in its retreat erratic bowlders that may have been carried across divides from distant sources. The San Gabriel Mountains, instead of exhibiting these phenomena, have many projecting rock pinnacles, are covered with the detritus of rock decay, are free from rock basins and lakes, and have only bowlders of disintegration scattered over them.

If glaciers ride out upon the plains in front of the mountains in which they originate, they leave irregular heaps of unsorted rubble, angular bowlders, a hummocky topography, and deposits of till, a compact clay containing scattering glaciated rock fragments. The plains at the base of the San Gabriel Range are clearly unlike this. They are a series of typically developed alluvial fans; graded as stream-laid deposits always are, with waterworn but unstriated

bowlders, progressively finer as the distance from the mountains increases, and free from lakes or undrained depressions. There is no evidence whatever of glacial action in the material of which they are built up nor in its arrangement. Water has been the agent by which this material has been transported from its original position in the mountains to its present resting place in the basins, and in consequence the sands and gravels have always been saturated below a point where they could drain freely. This saturating water is in constant slow motion from the point where it enters the gravels, along some stream channel or at the mouth of a mountain canyon, to the point where it escapes from the basin over the lowest part of its rim. Its movements are impeded by the friction which it encounters in its passage through the fine pores, so that its surface is not level like that of a free body of water, a lake, or a sea, but slopes from the point of supply to the point of drainage. When supply is increased the slope is steepened by raising the surface of saturation at the point of intake. When supply is decreased by a lessened rainfall, the slope of the surface of saturation becomes flatter and the ground-water level falls, the lowering being more marked at a distance from the point at which the basin drains; for since this latter point controls the escape of water in the basin, its level remains practically constant.

CHARACTER OF THE ROCK FLOOR OF THE FILLED AREAS.

The surface of basins like the San Gabriel Valley or that east of the San Jose Hills is invariably a sloping plain, steeper near the mountains, more nearly level at greater distances from them, and varied only by minor knobs or local changes of slope. Red and Indian hills rise above the Cucamonga Plains; a number of bed-rock knobs in the neighborhood of San Dimas and Glendora project above the plain of waterworn material which lies between the San Jose Hills and the San Gabriel Mountains; San Dimas Wash, itself a late sand and gravel filling, lies between bluffs of older alluvium; the Raymond Hill "dike," which extends from Pasadena to a point beyond Santa Anita, is marked for much of the distance by an abrupt change of slope and in places by distinct knobs; and here and there at other points near the edges of the plain bed-rock knobs of shale or of gneiss rise above the general valley level. These projections are sufficient only to indicate the irregularity of the valley bottom; they do not enable us to restore the details of the irregularities. Well records generally do not indicate that bed rock has been reached in the borings, the wells usually being too shallow to accomplish this result. The deepest within the San Gabriel Valley—one drilled by

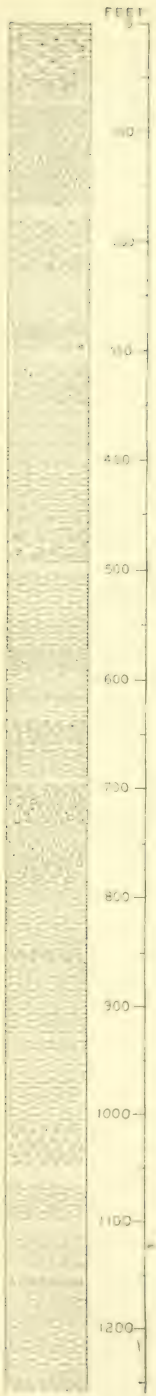

FIG. 1.—Section of well north of Woyden (No. 23), Pasadena quadrangle.

the East Whittier Company (fig. 1), north of Woyden station on the Southern Pacific Railroad—is 1,260 feet deep, and no bed rock was encountered, although the bottom of the well is almost 1,000 feet below sea level. Among the wells in the vicinity of Pomona of which records have been obtained are a number between 500 and 1,000 feet deep. One of the deep wells of the Irrigation Company of Pomona, situated in the old Palomares ciénaga, about three-fourths of a mile northeast of the point of the San Jose Hills, reached bed rock at a depth of about 800 feet. It was drilled 150 feet lower, but of course no water was developed in the deeper formation. Bed rock in this well is about 150 feet above sea level, as the surface of the plain here is about 950 feet above.

The Lorbeer well, 1 mile northwest of Chino, is 973 feet deep and extends nearly 200 feet below sea level without striking bed rock. The lower 500 feet of clays, many of them red and of cemented gravel, were dry and yielded no water. These strata appear to belong to the earlier alluvium rather than to the later, more effective water-bearing gravel series.

Half a mile southwest of this, a well belonging to Black Brothers & Woodhead is 718 feet deep and extends to within 25 feet of sea level. An incomplete record of this well fails to show the presence of strata older than the modern alluvium.

Some other wells near bed-rock hills strike the buried slopes of these hills, but generally those out in the plains and valleys penetrate only loose sands, gravels, and clays.

It may be accepted as true that the bed-rock bottoms of the valleys whose topographic details are concealed by the mantle of wash which forms the Cucamonga Plains and the San Gabriel Valley are irregular, just as the topography of those bed-rock areas which extend above the wash as hills is irregular. The rock basement beneath the San Gabriel Valley is presumably not unlike the hill region between Los Angeles and Pasadena in character.

An attempt to estimate the elevation of bed rock in the deepest part of the San Gabriel Valley is interesting but speculative. Since it is a valley of deformation, not one of erosion, a consideration of stream grades throws no light on the problem. A projection of the

mountain slopes on the north and south of the valley to some assumed point of greatest depth probably gives a maximum measure, since it is quite unlikely that the steep slopes of the unburied portion of the surrounding mountains are maintained for greater distances beneath the cover of wash than above it. Such a rude estimate gives 4,000 feet below sea level as a possible depth of the bottom of the San Gabriel basin 2 or 3 miles south of Monrovia. It is likely to be less than this. The deepest well in the basin is that owned by the East Whittier Land and Water Company. This well is just west of San Gabriel Wash and about one-fourth mile north of the main line of the Southern Pacific. No bed rock was encountered in it at a depth of 1,260 feet, or nearly 1,000 feet below sea level.

The Cucamonga Plains east of the San Jose Hills represent a more extended area than the San Gabriel Valley, and bed rock may be buried to a considerably greater depth beneath them. Wells in this area whose records have already been quoted extend to points well below sea level without encountering rock, but the outcropping Red Hills and Indian Hills, the barriers to which are due the old Martin and Del Monte ciénagas, the dry red clays and cements encountered in some of the deep wells between Pomona and Chino, and the traces of earlier alluvium which flank the west end of the Jurupa Mountains on the north, indicate that this formation may be of considerable importance under at least the western portion of the Cucamonga Plains. Beneath the northeastern part of these plains, where the alluvial fans are so steep and high, water is at too great a depth to be accessible, the underground conditions are little known and of little interest, and the depth to the bottom of the basin is purely a matter of conjecture. It has been estimated[a] that the San Bernardino basin may be 3,000 feet deep, or thereabouts. It seems unlikely, from the general evidence which has just been given, that the San Gabriel basin is more than 4,000 feet deep, and it may be less than this. The Cucamonga Plains area may overlie a bed-rock basin that is somewhat more deeply buried than either.

GROUND-WATER DISTRICTS.

Within the foothill belt the development of ground waters has been most intense in certain districts where experience has proved it to be most accessible and present in greatest amount, or where, despite the rather high cost of production, the crops raised by its use are valuable enough to bear easily the expense of pumping against high lifts. It is intended to present in the following paragraphs the essential facts, so far as they are known, as to the occurrence of the waters in each of these areas.

[a] Water-Sup. and Irr. Paper No. 142, U. S. Geol. Survey, 1905, p. 31.

RED HILLS WATERS.

The "Red Hills," so called, lie about 2 miles northeast of North Ontario and nearly 4 miles south of the base of the San Gabriel Range. As a physical feature they form a nearly flat-topped mesa, which interrupts the general slope of this part of the Cucamonga Plains.

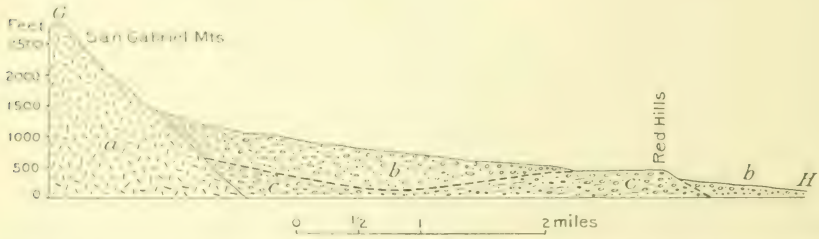

FIG. 2.—Diagrammatic section through the Red Hills: *a* granitic rocks; *b*, *c*, earlier and later alluvium and hypothetical boundary between them.

Approached from the north the mesa appears only as a lessening of the slope, but its southern edge is a scarp 50 to 150 feet high. The hills are made up of a deposit of the earlier red alluvium which has here escaped the destruction of the older topography by erosion during

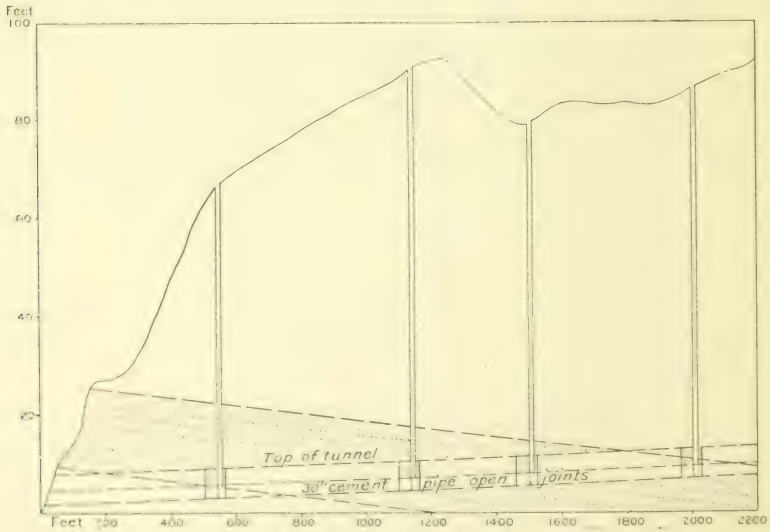

FIG. 3.—Section along line of the Eddy or Cucamonga tunnel.

the deposition of the later alluvium. The low mound therefore represents the top of a hill of red clay, sand, and gravel, whose slopes are deeply buried under modern wash (fig. 2). Indian Hill represents a similar outcrop, and the same red-clay formation is reported to show

between these two points. The Martin and Del Monte ciénagas are likewise probably due to buried hills of this older deposit which approach near to the surface. Its distribution beneath the modern gray alluvium therefore appears to be extensive.

This buried earlier alluvium affects the occurrence of underground waters in two ways. In the first place, where the hills of the older, concealed topography lie athwart a line of underground circulation through the later alluvium, they serve as a dike or underground dam, forcing the waters which are percolating through the overlying gravels to or near to the surface, where they flow out in springs or are easily developed by wells. Or again, where the older alluvium lies near the surface the waters which circulate through it may be brought within reach of development. As the older alluvium has been folded in some localities by crustal disturbances which have taken place since its deposition, it may be that where it projects above the general plains surface it has been brought to this position by folding. The section of the Eddy tunnel through the base of the Red Hills near their western margin (fig. 3) seems to show a dip of the beds toward the north. It is probable, therefore, that this body of older alluvium stands above the general plain because it has been brought up along or near the axis of such an arch. Some of the waters which are percolating through it southward from the base of the San Gabriel Mountains will be brought to the surface at this point and will issue as springs, or where their volume is not great enough to force them out as springs, they will at least be brought near enough to the surface to be accessible and may be developed by pumps.

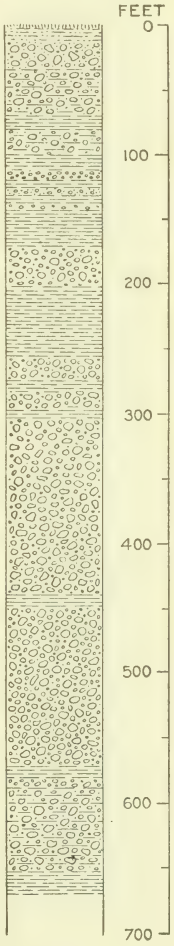

FIG. 4.—Section of Cucamonga Water Company's well (No. 69, Cucamonga quadrangle).

As a matter of fact, the vicinity of the Red Hills has been a source of irrigation water since the settlement of this part of southern California. Originally the waters utilized rose to the surface, principally in the "East" and "West" ciénagas. The West ciénaga lay along the west base of the Red Hills and the East ciénaga in a ravine which drains southward from a point east of the highest part of the mesa, but near the center of the outcrop of the red alluvium.

As the colonies dependent on these waters expanded, several devices were adopted for increasing the output of the water-bearing land.

The Y tunnel was driven into the hill east of the East ciénaga in 1886 and 1887. Another tunnel, three-fourths of a mile farther east, was driven into water-bearing ground in 1887 and 1888, and the Eddy tunnel was extended under the West ciénaga at about the same time. More recently, especially in the late nineties and since, many wells have been drilled and pumping plants installed to increase or to maintain the original supply.

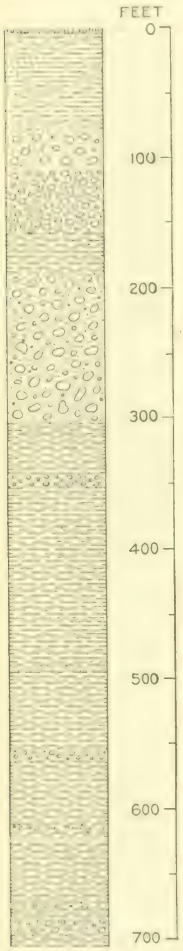

FIG. 5.—Section of Sunset Water Company's well (No. 54, Cucamonga quadrangle).

The original ciénaga waters and the pumped waters which now take their place seem certainly to be derived both from the earlier and later alluvium. The ultimate origin of the water in each of these formations is the same—namely, the rainfall upon the San Gabriel Range, north of the Red Hills—but the courses which they follow to the point of development, or at which they originally issued, are probably essentially different. Nevertheless, waters from both sources were no doubt mingled in the old springs and are probably now mingled in some of the wells.

It is to be remembered that the Red Hills as a partially buried topographic feature act as a barrier against which the modern stream wash has been piled. (See fig. 2.) The waters which are percolating southward through this wash reach the barrier, rise behind it, and flow over it as springs, except where they are taken out by development before they reach the surface. Waters within the older formation, the red alluvium of the hills, enter the porous beds of this terrane at points near the base of the mountains, follow a deeper and presumably longer course entirely below the modern wash, and rise along the fold which is expressed by the Red Hills, to escape as springs or to be taken out before their escape by development. Important evidence of this difference in the courses followed by the two groups of waters is furnished by their temperatures. The waters of the east-side wells issue at temperatures of 70° to 72°; those of the west-side wells have temperatures of about 64°. This difference of 6° or 8° indicates that the former waters rise from regions 350 to 400 feet deeper than the latter, if the usual increment of 1° increase in earth heat with each 60 feet in depth is accepted as applying in this region. Inasmuch as the increase is probably less rapid than this in these unconsolidated gravels, it is likely that the difference in the

depth from which the two waters rise is greater than that given above. If this evidence of the temperature is accepted as a safe basis for a division of the waters, the Haskell wells (No. 79, Cucamonga quadrangle) and those farther east fall into the group which derives its waters from the Red Hills formation, the older alluvium; while those to the west derive their waters from the overlying modern wash. The location of the wells in areas which are recognized as respectively in older and in modern alluvium supports this evidence of the temperatures.

It is unlikely that the waters of the two groups are wholly distinct. Interchange probably takes place through leakage from one formation into the other. However, even though the separation is not entirely perfect, it is probably sufficiently definite to bring about certain differences in the behavior of the two groups of waters under the influence of development. The supply in the west-side wells may be expected to respond somewhat more promptly to wet and dry years than that of the east-side wells, whose waters follow a longer course through somewhat less pervious material to the point where they are pumped to the surface. In many places, also, the older gravel is less open and yields its waters less freely than the newer, so that individual wells are expected on the average to have a smaller capacity. The water developed from both formations in the vicinity of the Red Hills is probably supplied largely by the run-off from Cucamonga Canyon and the canyons farther east.

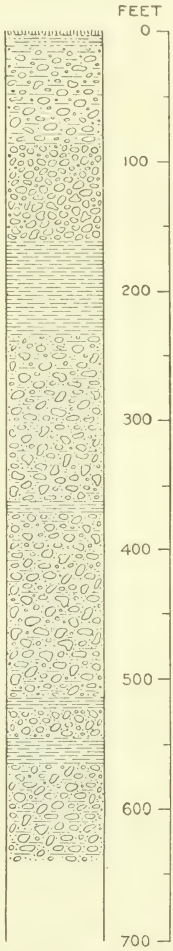

FIG. 6.—Section of San Antonio Water Company's well (No. 73, Cucamonga quadrangle).

SAN ANTONIO UNDERGROUND WATERS.

The area whose ground waters are supplied by run-off from San Antonio Canyon is so distinct and so important that it is best to accord it separate treatment. The Palomares, Del Monte, and Martin ciénagas, at one time prolific sources of artesian water and still yielding valuable pumped waters in large quantity, the Indian Hill group of wells, and another series of scattered wells near the San Gabriel foothills northwest of Claremont all draw the major part of their waters from the run-off of the San Antonio basin and the much smaller and less important basins of Thompson and Liveoak creeks. Their situation, which has been determined as

most favorable by years of work in development, is in the belt through which practically all San Antonio waters must percolate. The peculiar position of the old Palomares ciénaga, on the high ground at the eastern point of the San Jose Hills and apparently not in the direct line of run-off from any of the important canyons, together with the abundant water supply which it has always yielded, makes it of especial interest. Practically all of the surface discharge of San Antonio Canyon now passes east of Claremont, and the run-off from the next large canyon to the west—San Dimas—is entirely westward toward the San Gabriel. The Palomares ciénaga is nearly on the divide between them. Apparently the only element in its situation favorable to the formation of an artesian basin is the barrier of the San Jose Hills back of it. Surface conditions alone would lead the student of the ground-water supply to expect the greater part of the San Antonio percolation to be well east of Claremont, but development proves that it is practically all west of a line which crosses the Santa Fe Railway about 1 mile east of the town.

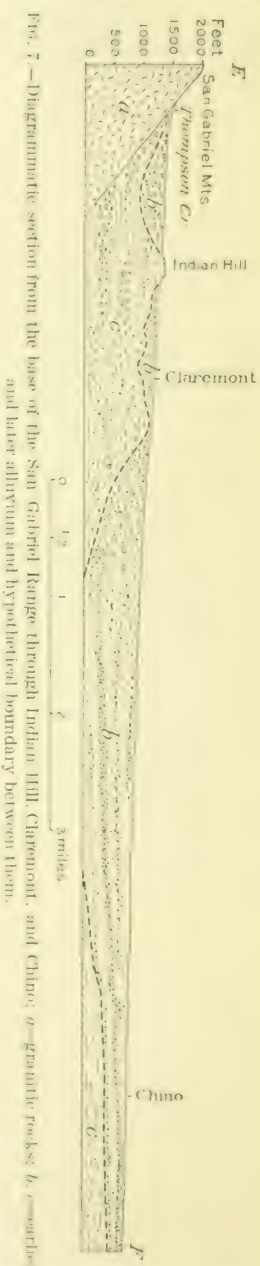

FIG. 7.—Diagrammatic section from the base of the San Gabriel Range through Indian Hill, Claremont, and Chino; *a*, granitic rocks; *b*, earlier and later alluvium and hypothetical boundary between them.

The true explanation of this diversion of the San Antonio percolating waters westward against the foot of the San Jose Hills, when their normal course apparently should be directly southward from the mouth of the canyon, is to be sought in the buried older topography (fig. 7), which has been discussed in part in the consideration of the Red Hills waters. The evidence furnished by well records, which is rather scant, and by water levels, also scant but yet more complete than the other, indicates that a barrier (a so-called "dike"), which is probably only a buried hill of the older alluvium, extends from the base of the spur east of the mouth of San Antonio Canyon southward and slightly westward in a gentle curve toward the south line of the Palomares ciénaga and the east point of the San Jose Hills. West of this curved line lie the producing wells of the district, with a water plane high enough, except at some points near the base of the mountains, so that the waters may be pumped

readily; east of it are many dry shafts, or if water is encountered it is at a much greater depth than across this line. Underground waters from the Cucamonga Canyon are checked and held up so that they are accessible by the Red Hills and by buried northwest and northeast extensions of them, while the same effect is produced on the San Antonio Canyon waters by the buried ridge indicated above.

Between these two valuable water-bearing districts is an irregularly triangular area, with its axis perhaps a quarter or a half mile west of San Antonio avenue and its base extending along the Santa Fe tracks, in which ground waters are found only at depths too great for profitable development at present. This is presumably a valley in the earlier buried "Red Hills" topography, and the underground waters entering it across the buried ridges or "dikes" to the northeast and northwest sink at once to lower levels, much as surface waters are found at lower levels below a dam than above it.

The first waters taken from the old Palomares ciénaga (Pl. I, *C-D* and fig. 8) were waters which rose naturally under artesian pressure and supplied San Jose Creek. These waters were diverted into a ditch and used for irrigation as early as 1840. The use was not extensive, however, until the seventies, when the available amount was increased by developments consisting of drainage ditches cut into the ciénaga and of artesian wells. These wells continued to yield a supply until near the end of the decade between 1890 and 1900, when they gradually failed as a result of increased development and drought. Now all waters drawn from this original artesian basin are pumped. The smaller Del Monte and Martin marshes have had similar histories. They first yielded spring waters; then with the "development" of the water-bearing lands, short-lived artesian wells were procured and the springs dried out. Now all water used is pumped.

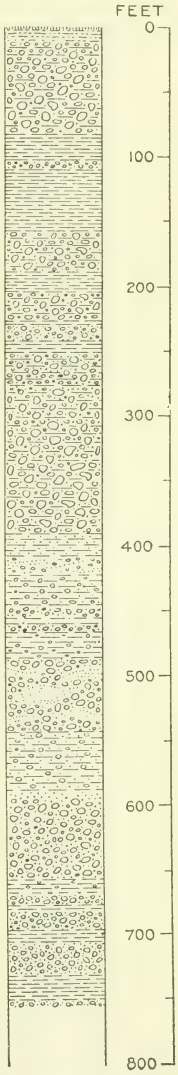

FIG. 8.—Section of Gird well No. 6, Palomares ciénaga (near No. 284, Cucamonga quadrangle).

CHINO ARTESIAN BELT.

All the waters which escape underground from the higher water-bearing lands to the north, all the return irrigation waters from the extensive irrigated areas about Pomona, Claremont, Ontario, and

Cucamonga, and the winter flood waters from the mountain canyons between Lordsburg and Etiwanda which are absorbed south of a line connecting the eastern part of the San Jose Hills and the Red Hills, percolate slowly southward, toward Santa Ana River, the main drainage line of this part of the State.

In the vicinity of Chino and for 5 or 6 miles southeast of that town these ground waters are under sufficient pressure to rise to the surface when wells are drilled in the water-bearing sands. The area within which these rising waters are known to occur covered about 21.4 square miles in 1904. This represents a slight shrinkage from the maximum original area of approximately 23 square miles, when the basin was entirely undeveloped and rainfall in this part of the State was heavy. The southwestern rim of the basin is formed by the bed rock of the Puente Hills. Toward the northeast it is indefinitely limited by the rising ground of the Cucamonga Plains. Its southern edge, so far as it is revealed by development, is a rather difinite line that is probably determined by the shoaling of the basin in this direction, through the rise of its relatively impervious base toward the surface. This base seems to consist of an older gravelly alluvium, like the coarser phase of the Red Hills beds, but beneath this Tertiary sandstones and shales or granitic rocks such as outcrop near Corona would doubtless be encountered in sufficiently deep drilling.

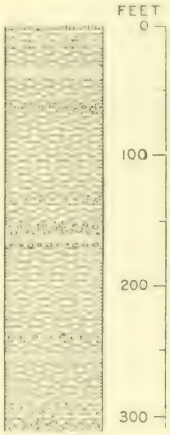

FIG. 9.—Section of W. P. Brown's well (No. 221, Cucamonga quadrangle).

Throughout this belt, as in most of the artesian districts, there are moist lands and springs that mark the points at which the waters under pressure below leak to the surface. Chino Creek and other small streams which drain the area do not show the usual shrinkage of southern California streams during the last decade, but on the contrary have maintained their flow or have increased it slightly. Santa Ana River at the narrows below Rincon has increased in flow from a minimum of 14 or 15 second-feet in 1888 to a minimum of 60 or 70 second-feet in 1904. This increase is accepted as one of the striking examples of the effect of return irrigation waters in adding to the volume of flowing waters below the irrigated lands during a dry period. Much of this increase is no doubt due to irrigation in the vicinity of Riverside, but an important proportion is also to be attributed to the steady application of water to the land in the colonies along the western margin of the Cucamonga Plains. A large part of this latter return water passes through the Chino artesian belt in its slow percolation seaward, and helps to account for the fact that this basin has exhibited less shrinkage during the trying years of

drought which have just passed than other important artesian basins of this end of the State. It is also true that this basin has been less vigorously developed than others, chiefly because there has been difficulty in securing good titles to land on the old Chino rancho until recently. These two conditions, then, moderate development and favorable situation in relation to return irrigation waters, account for the fact that this basin is now in excellent condition so far as its water supply is concerned.

The Chino basin proper has not been explored to great depths by the driller, the deepest well being that belonging to Edward Lester (No. 36, Cucamonga quadrangle). It is 467 feet deep, and all the coarser strata are found above 390 feet. Most other wells within the basin are 300 feet or less in depth. (See fig. 9.)

The deepest well in the Cucamonga Plains, the Lorbeer well (fig. 10), just northwest of Chino, was drilled to a depth of 973 feet, but the record indicates that below 500 feet the drill pierced the older alluvium, consisting of red clays and cemented beds which yielded no water. Southwest of Chino, toward Santa Ana River, there are outcrops of slightly hardened gravel which seem to belong to the earlier alluvium. These scattered facts suggest that the filling of modern wash within the Chino district is a comparatively thin veneer, 500 feet or less in thickness, beneath which lie relatively compact older clays and cemented gravels which are dry or but meagerly water bearing. If this inference is correct, the value of wells drilled in this region in the future will not be increased by extending them in depth beyond 300 to 500 feet. The data are too incomplete as yet to state this as more than a probable condition. A few deep test wells drilled in the area extending 4 or 5 miles southeastward from Chino will give much needed light on the underground conditions.

The apparent shallowness of this basin, taken in connection with the rather irregular topography along its southern border in the vicinity of Saant Ana River, leads to the belief that its limits in this direction are due to the rise toward the surface of

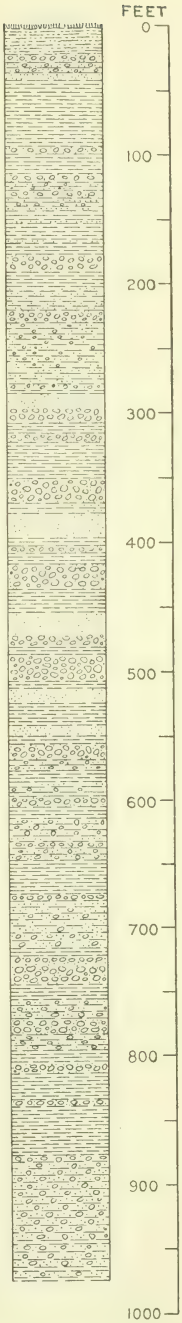

FIG. 10.—Section of Lorbeer well (No. 154, Cucamonga quadrangle).

the dry older alluvium which forms the floor of the basin farther north.

SAN JOSE VALLEY.

The Puente and San Jose hills, which together constitute the northwestern extension of the Santa Ana Mountains, are separated by the valley of San Jose Creek. This stream is peculiar in that it rises not in the hills themselves but in the western edge of the Cucamonga Plains, whence it flows directly across the hill area through a restricted valley into the San Gabriel basin. It is believed to be a compound stream, resulting from a reversal of drainage caused by the growth of the San Antonio alluvial fan. The original divide between the eastward-flowing and westward-flowing elements of this compound stream seems to have been about 2 miles below Spadra. At that time the east end of San Jose Valley drained into the Santa Ana, and the west end drained as now toward the San Gabriel. With the growth of the San Antonio fan southward the original eastern outlet was blocked, slowly filled, and finally given a westward slope. The Palomares ciénaga probably originated with this growth of alluvial deposits and its excess waters became the source and principal feeder of San Jose Creek. Now, when there is a surface flow in this creek, its waters rise on the north slope of the eastern point of the San Jose Hills, flow westward around the point of the hills, and double back into the San Jose Valley, giving a very tortuous alignment to the upper portion of the stream.

The sand and gravel filling in the eastern portion of the San Jose Valley in the vicinity of Pomona is rather deep; wells have been drilled here to depths between 300 and 400 feet without reaching bed rock. Near Spadra are wells between 150 and 300 feet deep which do not reach the rock bottom of the valley, but others much shallower near the borders of the area encounter rim rock, the "hill formation," as it is locally called. In the vicinity of Lemon bed rock seems to be near the surface of the valley. In the Howell well and tunnel the hill shales are found at a depth of 35 feet, but the McClintock, Lee & St. Clair well, 1 mile farther south, failed to reach rock at 100 feet. From this neighborhood westward the valley presumably deepens gradually until it unites with the main San Gabriel basin below Puente. Its underground water supply, while replenished in part, of course, by local run-off from the surrounding hills, has been fed in the past to an important extent by the excess from the Palomares ciénaga, which San Jose Creek drains, and that supply has, with but little question, been adversely affected by the extensive drafts on this ciénaga for irrigation about Pomona.

SAN DIMAS DISTRICT.

DEVELOPMENT.

West of the Cucamonga Plains and between the San Jose Hills and the base of the San Gabriel Range is an area, extending westward to San Gabriel Wash, which has been growing steadily in importance in recent years as a productive citrus district. It includes the towns of San Dimas, Covina, Glendora, and Azusa, with their surrounding tributary horticultural belts.

The preservation of the citrus acreage planted previous to 1897 and its extension since have been accomplished here, as in most of the orange-growing sections of the south end of the State, by the development of underground waters. To bring about this result many important wells have been put down during the last decade. This development has been particularly extensive in San Dimas Wash because valuable lands about Glendora and Covina could be conveniently served by these waters, and on the mesa lands about Laverne because this region is especially adapted to citrus culture and is not served by gravity waters from either the San Gabriel or the San Antonio system. The flowing waters from the smaller canyons between these two streams are of course utilized, but the flow from them ceases or seriously diminishes during the heated term, and must be augmented by ground waters to provide for the continuous irrigation which citrus fruits require. This development has resulted in the accumulation of a considerable mass of evidence on underground conditions, and inasmuch as a large acreage is dependent on waters obtained by pumping, great interest is felt by the dependent communities in the conditions which the developments reveal.

SURFACE CONDITIONS.

The red mesa lands, which represent the older topography of the Indian Hill and Red Hills type, are widely distributed in this narrowest part of the valley between the San Jose Hills and the San Gabriel Mountains. They form the mesas on either side of San Dimas Wash, which is, indeed, a canyon cut in this older alluvium and then partially refilled by the modern stream débris; they extend from San Dimas eastward beyond the mouth of Liveoak Canyon and southward toward Laverne and Lordsburg. In the latter direction their surface extent can not be determined with accuracy because they are mantled by the later alluvium, and the soils derived from the two formations are very commonly so much alike that they can not be distinguished. The obscurity is increased where the older mesa formation is coarse and gravelly, as it is in numerous places near the mountains. In many such places its red color is wanting and it is to

be distinguished from the latest wash only by its distribution and by a slight induration, which although very imperfect is usually somewhat greater than that of the later gravels. North of San Dimas Wash a bench of the red clays, in many of the exposures very typically developed, extends eastward from the point of the hill south of Glendora to the base of the main range. Between Azusa and Glendora a fringe of this formation flanks the mountain base. In these described areas it forms the actual surface; over other sections it is probably not deeply buried. For example, it presumably underlies the entire area about the head of Walnut Creek, extending from Laverne, San Dimas, and the country to the west, southward to the San Jose Hills, and it may underlie much of the Glendora district at slight depths. It should be understood clearly that these red clays and gravels were distributed just as the clays, gravels, and sands are being distributed to-day over their channels by the San Gabriel and other streams. In both cases the material laid down is simply the ground-up rock brought by the streams from their mountain canyons, and the total quantity of earlier and later wash is equal to the amount removed by the streams in cutting the canyons.

The important facts about the older alluvium are that in certain areas it has been uplifted since its deposition and that time enough has elapsed to permit it to be eroded by the streams since its uplift, so that an irregular topography has been produced in it. There are hills here and valleys there, canyons in one area, mesas in another, and these have all been smoothed over and partially buried by the modern stream wash. We do not know this older topography, therefore, in detail. We see only here and there a hilltop or a broad mesa standing above the modern wash. The rest of the red alluvial hills and valleys are buried beneath it. In many areas, however, they manifest themselves distinctly in the influence that they exert on the circulation of the ground waters. While this influence is marked, it is not everywhere complete, because the old alluvium is not impervious. A ridge of it buried in the later alluvium may therefore not entirely deflect the waters percolating through the latter, although the difference in porosity is in many places great enough to make the deflection nearly complete.

Both the older and the younger alluvial deposits exhibit the irregularity which is characteristic of the alluvium everywhere. Both have their coarse and their fine phases, their pervious and their impervious lenses and strata. This fact increases the difficulty of distinguishing between them, because though, taken all in all, the modern wash is more open and permits of freer circulation of ground waters than the older wash, yet many of the better beds in the older wash may be superior to the poorer beds in the modern wash in this important respect. Both are water bearing, and under favorable conditions good wells are procured in each, but the greater number of better wells

are drilled in the modern gray wash, and in many places the older alluvium is dry.

UNDERGROUND CONDITIONS.

The extensive developments about Lordsburg and Laverne and in San Dimas Wash have brought to light certain important phases of the underground conditions. Bed rock has been found in enough of these wells to give a hint as to the depth of the alluvial filling and the downward limits of water-bearing gravel. A well which has been mentioned before, belonging to the Irrigation Company of Pomona (No. 182, Pomona quadrangle), enters bed rock at a depth of about 800 feet; that is, at 160 feet above sea level.

In one of the Covina Irrigating Company's wells south of Lordsburg the drill entered lava, similar to that which outcrops in the hills farther to the south, at 244 feet from the surface, although other wells of this group which were drilled 150 feet deeper are in alluvium to the bottom.

In the recently drilled Peyton well (No. 247, Pomona quadrangle; see fig. 11) a granite bed rock, first encountered at 538 feet from the surface, was penetrated for nearly 100 feet. Bed rock here stands at something more than 600 feet above sea level and in the Covina well at about 750 feet.

The San Dimas Irrigating Company's wells on the site of the old "Mud Springs" ciénaga reached a shale bed rock at about 200 feet below the surface; that is, at about 800 feet above sea level. These and the Covina wells are near the south rim of the valley.

At the bottom of wells Nos. 208 and 210, owned by Baker & Son and by N. L. Sparks, a lava bed rock was found at 330 and 300 feet, respectively, below the surface; that is, at a little less than 900 feet above sea level. North and south of San Dimas Wash are bed-rock hills of shale, sandstone, and lava, and wells drilled near these knobs strike the same rock formation at slight depth. The Deacon wells, belonging to the Covina Irrigating Company, are of this type. Of the wells mentioned none are in the center of the valley, where bed rock is probably deepest, although the Peyton well, north of Lordsburg, is not far from the center. A number of the San Dimas Wash wells are more than 500 feet in depth (fig. 12), and so far as reported, in no well except those of the Deacon

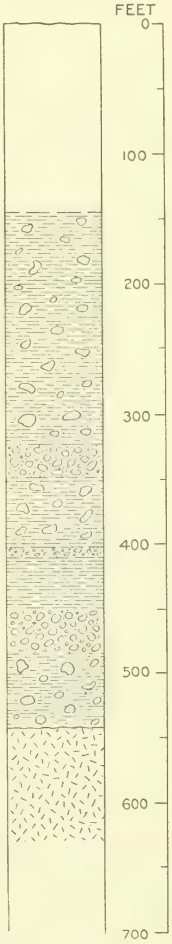

FIG. 11.—Section of Peyton well (No. 247, Pomona quadrangle).

group, drilled near the base of a bed-rock mound, was rock found in place. It seems unlikely, however, that bed rock is more than 1,000 feet below the surface in this vicinity. The buried bed-rock surface, it is to be remembered, is probably quite as irregular as that part of it which lies above the alluvial filling. It consists of ridges, knobs, and valleys, so that the depth to it will not be uniform and can not be predicted with exactness at any point. The records of the wells which have been mentioned support the opinion that would be formed by a mere inspection of the topography, namely, that bed rock lies closer to the surface in this narrow belt, where the Coast Range approaches nearest to the base of the San Gabriel Mountains, than in the broader San Gabriel Valley to the west or in the wide Cucamonga Plains to the east.

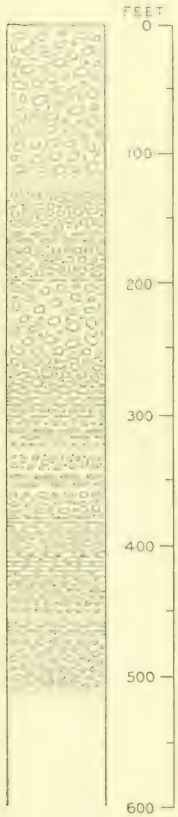

FIG. 12.—Section of Western Water and Power Company's well No. 23, Pomona quadrangle.

The greater part of the sands, gravels, and clays in the San Dimas area belongs, as has already been indicated, to the older alluvium, the "Red Hills formation," as it is locally called; but in San Dimas Wash itself a fairly deep canyon has been cut into this older wash and then partially filled again by the loose sands and gravels brought out by the stream (fig. 13). The walls of the unfilled portion of this older canyon limit the mesa north of San Dimas and Laverne.

The depth of the loose modern filling in the wash seems to be only about 100 or 200 feet. Below that depth some of the wells encounter red clays which presumably belong to the older alluvium that forms the walls of San Dimas Wash.

The depth to bed rock in the wash is of interest to irrigators because it determines the final lower limit from which irrigating waters can be drawn. None of the owners who have put down wells near the middle of the wash, where the freest water-bearing gravels are found, have reported bed rock, although it has been reached in a number of the wells near the southern edge. In view of the restricted character of the middle valley of the San Dimas and the fact that it is only about 1 mile from rim rock on the south of the wash to rim rock on the north, near the town of San Dimas, it is manifest that bed rock can not lie at great depth below this part of the stream bed.

North of Laverne the valley is broader and may be deeper, since its bottom is probably irregular, but the greatest depth to bed rock

here is probably beneath the mesa in the old alluvium, while the principal producing wells lie in the wash within less than three-fourths of a mile from the northern rocky border of the valley. If the general average slope of this mountain rim, a slope of 1,000 to 1,500 feet per mile, is maintained beneath the wash, as it probably is, then bed rock is to be expected at less, probably at considerably less, than 1,000 feet from the surface in that part of the wash where development is most intense.

The great value of the gravels which have been pierced here is due to their coarseness, openness, and looseness, and the consequent freedom with which they yield the water that they contain, and the readiness with which they are recharged after having been heavily pumped.

The San Dimas area forms the extreme eastern extension of the San Gabriel Valley, but has been discussed as a separate district because of the intensity and importance of its development, and because, as it stands near the divide between the San Gabriel Valley

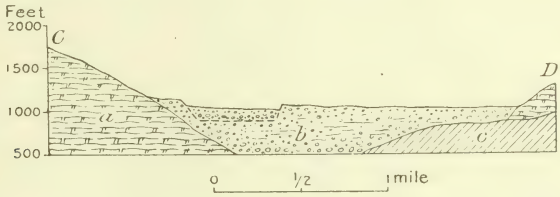

FIG. 13.—Diagrammatic section across San Dimas Wash; *a*, lava; *b*, alluvium; *c*, shale.

and the Cucamonga Plains, underground conditions are unlike those in either of the latter areas.

SAN GABRIEL VALLEY.

Westward from San Dimas the valley of San Dimas Creek gradually opens out into the San Gabriel Valley proper, which extends as a wide plain with a gentle slope toward the south to the San Rafael Hills beyond Pasadena. San Gabriel River at the mouth of its canyon discharges upon this plain and leaves it through the Paso de Bartolo, a dozen miles to the southwest. Throughout much of the year its channel across the plain is a dry wash, but during the period of the winter rains a surface stream often extends entirely across the valley. At other seasons the water which reaches the inner edge of the plain from the canyon sinks and crosses the valley by percolation underground. Water always rises in and near the Paso de Bartolo in springs, which feed Rio Hondo and the San Gabriel and thus supply the canals which head here with irrigating water. So far as known, this central portion of the basin is a simple broad valley of deformation, whose bed-rock bottom may be several thousand feet below the surface.

That part of the San Gabriel Valley, however, which lies north and west of a line connecting South Pasadena with the spur of the San Gabriel Mountains between Santa Anita Canyon and Monrovia, is a distinct province so far as its underground waters are concerned. A fold in the late strata which form the valley filling, a fold which in places expresses itself topographically as a ridge or a series of knobs, here forms an effective underground barrier to the waters that are percolating toward the axis of the valley from the northwest, and so makes of this northwestern tract a distinct area, which will be spoken of as the Pasadena Basin.

In the central part of the San Gabriel Valley development has not as yet been very intense. The cultivable lands along the northern edge, particularly those east of San Gabriel Canyon, are irrigated largely by canals which take gravity water from the canyon. There are a number of successful wells west of the wash close to the foothills, where soils are good, but farther south is a wide area of rough land which has little agricultural value and beneath which the water plane lies at considerable depths. Still farther south, toward Bassett and Elmonte, the soils are finer and more productive, and the water plane lies nearer the surface, so that the development of underground waters is less expensive. In this area they are more generally used. The Paso de Bartolo is the water gap through which the San Gabriel Valley waters are discharged upon the coastal plain. It is less than 2 miles wide, and its depth is not known, although the topography and the records of wells drilled in the pass indicate clearly that the depth must be considerable, perhaps 600 or 800 feet. The valley to the north is doubtless much deeper than this, and the rise of the ground waters in the pass is due to a combined lateral contraction and shoaling of the basin, so that the cross-section of the field through which the waters are percolating is very much lessened, and they are forced out as surface flows. The waters which accumulate here above the pass and escape through it, either over the surface or beneath it, include all the waters that drain into the San Gabriel Valley from San Dimas westward to Pasadena, except those that evaporate from the water or soil surfaces. The greater portion of the subsurface circulation of even Arroyo Seco probably escapes to the coastal plain by this route, although its surface waters join the Los Angeles River system at Los Angeles.

The greater San Gabriel basin, in which the absorptive gravels occur, is a constructional valley of the type almost universal in southern California. It is one of the more extensive of the basins of this type, and its dimensions are difficult to estimate. Wells are not numerous except near the southern margin, and these are generally of depths so moderate that they give no clue to the position

of the bottom of the basin. One exception is to be noted. The test well of the East Whittier Land and Water Company, just west of San Gabriel Wash and north of the Southern Pacific tracks, has been extended to a depth of 1,260 feet. Throughout this distance the drill penetrated only alternating sand, gravel, and clay strata. The coarsest beds were found between 70 and 350 and between 570 and 780 feet from the surface. Below 780 feet coarse strata are unusual and clay predominates, but the bottom of the well is in unconsolidated material, bed rock not having been reached.

Wells 300 feet deep in the narrowest part of the Paso de Bartolo likewise failed to reach bottom, so that this outlet of the San Gabriel Basin has been depressed since it was cut by the stream until it stands below sea level. Just below and west of the pass, on the inner slope of the coastal plain, is a 500-foot well which penetrates alluvium throughout.

At Elmonte a well belonging to the Southern Pacific Company is 480 feet deep, and of course is in alluvium to the bottom. Other wells from 300 to 500 feet deep in the vicinity of San Gabriel and Savannah record the same conditions.

East of the San Gabriel and 3 miles north of Puente is a well belonging to Edward Fickewirth which is 850 feet deep (fig. 14). The record shows only an alternation of sand, clay, and gravel strata, but some of the gravel is reported to be cemented and may belong to the Pliocene rocks, which outcrop in the Puente Hills only a mile away. Shallower wells near this one are reported to yield more freely. In general the developments have furnished no evidence which will permit a direct estimate of the position and character of the rock floor of the San Gabriel Valley. It certainly lies well below sea level, not less than 1,000 feet below at the East Whittier pumping station, where the land surface has an elevation of about 300 feet. Without exploration to it, statements as to its position can have little value. The basin is too broad and irregular in outline to make projection of the slopes of the bordering hills a safe guide to the position of bed rock beneath the surface, and the existence of a fault or fault zone of great magnitude along the northern border adds to the uncertainty of the bed-rock position in this direction. It is highly probable that the depression of valleys of this type has been gradual, and that the filling by unconsolidated materials has also been gradual, since it has, no doubt, accompanied the depression and has probably kept pace with it. The more deeply buried sands and gravels are therefore the older, and their consolidation is likely to be more thorough. It is quite possible that alluvial sedimentation of this type began toward the end of the Tertiary period, which is represented in the folded conglomerates, shales, sands,

and clays in the Puente Hills, and that it has continued with more or less regularity since. If this is true, bed rock beneath parts of the valley, at least, will not be a distinct and easily recognizable feature.

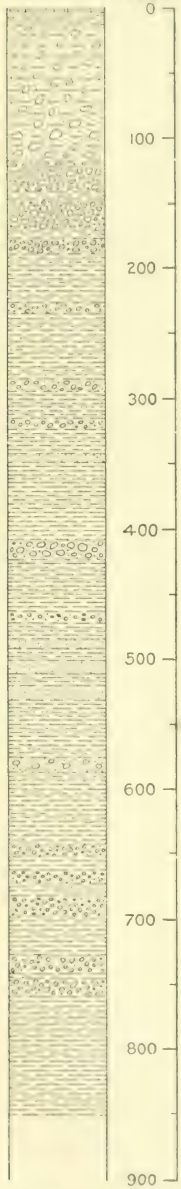

FIG. 14.—Section of Pickering well (No. 99, Pomona quadrangle).

Instead, in deep drilling, the late alluvium would gradually become more compact with depth until it passed by imperceptible gradations into bed rock of the type which outcrops in the Puente Hills.

Wherever granitic islands stood up from the deeper-lying granitic basement, however, and were finally engulfed only in the latest accumulations of alluvium, they may be encountered by the drill in its explorations, and then a perfectly distinct and definite bed rock will be recognized. Such a granitic island which projects above the present surface is to be found in Monk Hill, Pasadena, and others which lie beneath this surface are more likely to be encountered in drilling near the northern and western than near the southern and eastern edges of the basin.

PASADENA BASIN.

The Raymond Hotel stands on the crest of a hill near the southern edge of Pasadena. The axis of this hill is an overturned anticline of Miocene sandstones and shales. (See fig. 16.) North of east from the hotel are a series of low knobs and abrupt changes in the valley slope, which extend toward the spur of the San Gabriel Range that lies just east of the mouth of Santa Anita Canyon. At some points along this line the knobs and the steepening slope which are the surface evidences of certain significant underground conditions are conspicuous. At other points they are insignificant, but even here the topography is usually uneven and the zone along the upper edge of the "dike" is marked by dark peaty soil.

The behavior of the underground waters which are seeking an outlet by percolation southeastward from the Pasadena Basin toward the main San Gabriel Valley is even more significant of underground conditions along this line. Above it ground waters lie near to the surface or flow out over the surface in certain places. Below it they lie more than 100 feet lower. The condition is similar to that above and below a surface dam, the water level being much higher above than below because of the imper-

meable barrier between. Over the face of this subterranean dam, the Raymond Hill dike, the ground-water level has a steep grade, as surface waters have a steep fall over the crest of a surface dam. Above the dike percolating waters are checked in their southward movement and accumulate under pressure where proper physical conditions exist, so that they are artesian.

The greater number of the wells of the Pasadena Basin are located along a zone just above this dike, for the waters here are much more accessible than elsewhere in the basin. A few important wells, all of which, however, involve high lifts, have been installed in a subdivision of the main Pasadena Basin, near its northern edge, which may be spoken of as the North Pasadena Basin. Among these are wells belonging to some of the Pasadena water companies in the neighborhood of Las Casetas and Marengo.

On the mesa just northwest of Devils Gate one of the Pasadena Lake Vineyard Land and Water Company's wells (No. 434, Pasadena quadrangle) is 614 feet deep and does not reach bed rock, although rock outcrops in Arroyo Seco, only a mile away. This illustrates the steepness of the buried bed-rock slopes in this part of the Pasadena Basin. They are probably comparable in steepness with the mountain slopes to the north of the valley. The record of this well indicates a very common succession of sand, gravel, clay, and bowlders to 560 feet. Below that point the proportion of what the driller calls "rock," a term which he generally applies to very coarse material, increases and continues to the bottom of the boring. It seems unlikely that bed rock lies at a great distance below the bottom of this well.

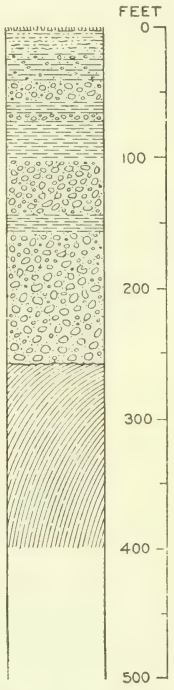

FIG. 15.—Section of Graves & Bean well (No. 449, Pasadena quadrangle).

Monk Hill (fig. 16), in North Pasadena, is a bed-rock outcrop which is clearly a southeastward continuation of the spur of the San Rafael Hills through which Arroyo Seco has cut at Devils Gate. This partially buried ridge is thus an eastward extension of the south wall of La Cañada Valley. Its presence is clearly indicated not only by the accumulated underground waters north of it which have been utilized with such success in the Devils Gate developments of the Pasadena companies and the wells about Las Casetas station, and by the much greater depth (200 feet or more) at which waters are found below it, but also by the records of wells Nos. 74 and 74a, which are reported to have reached bed rock at 135 and 146 feet, respectively, from the surface. These wells lie between Monk Hill and

the granitic outcrops in Arroyo Seco below Devils Gate (Pl. II, *A*) and furnish practically conclusive evidence that a continuous bed-rock ridge lies buried under the alluvium between these two points. The effect of this barrier is to check the southward movement of the underground waters which accumulate above Devils Gate, and to force them to make a long detour to the eastward around Monk Hill before continuing southward. They are thus thrown into the San Gabriel drainage basin instead of being tributary to that of Los Angeles River as are the flood waters of Arroyo Seco. An underground barrier thus changes entirely the route followed by the underground circulation of the upper course of the stream, and we have the interesting spectacle of the surface flood waters of a drainage basin flowing seaward by way of one river system, and the underground waters seeking the same destination by another route.

Before the Devils Gate developments were undertaken, some of the surplus underground waters which were held behind this Monk Hill barrier rose to the surface at Devils Gate in the series of springs which formed one of the important original sources of Pasadena water. This surplus is now taken out by the tunnels and wells and the springs have ceased to flow. It is safe to say also that more water may be continuously developed by this system than the springs originally yielded, because much was lost by evaporation in the moist lands about the springs under the original conditions, and also because a part of the surplus which originally no doubt found its way eastward around Monk Hill is probably now brought out by way of the tunnels and wells. At the Sheep Corral springs, as at Devils Gate, Arroyo Seco cuts through a spur of the San Rafael Hills so that its canyon becomes narrow, with rock walls and bottom impermeable to percolating waters. These waters are thus forced to the surface—or were before they were intercepted by development work—and appeared as springs. The situation is less favorable here than at Devils Gate because the Monk Hill bed-rock ridge deflects much of the ground waters eastward away from Sheep Corral, and it is probable that the developments there are supplied in an important measure, perhaps almost entirely, by those Arroyo Seco flood waters which are absorbed in the wide part of the arroyo which lies between Devils Gate and Sheep Corral. At both points submerged dams have been built to bed rock across the narrow part of the arroyo to hold back the underground waters or to force them to the surface. (Pl. II, *B*.)

One of the group of four wells belonging to the East Pasadena Land and Water Company on Franklin avenue and California street is 736 feet deep, its bottom being almost at sea level. It is nearly a mile north of the dike and in its record there is no trace either of the sandstone which underlies Raymond Hill or of the crystalline

A. DEVILS GATE.

B. SUBMERGED DAM ABOVE DEVILS GATE.

rocks which appear in the vicinity of the Sheep Corral springs. Sand, clay, and gravel, such as constitute the general basin filling, are reported clear to the bottom of the boring.

The deepest well reported in the Pasadena neighborhood is one drilled on the Hurlburt place near the south end of the city, just east of Orange Grove avenue. The depth given is 1,300 feet, and it is stated that much of this distance was bored through "granite." Details are not available, however, and as the well is near the western border of the basin, where bed rock is to be expected at comparatively shallow depths, it has no especial significance. A few of the wells drilled near Raymond Hill, as for instance No. 53, belonging to the Euclid Avenue Water Company; No. 448, belonging to the Pasadena Land and Water Company, and No. 449, of the Graves & Bean system, reach the shale or sandstone which appears at the surface about Raymond Hill, but is buried farther east. Other wells drilled farther east along the dike, while numerous, are usually shallow, do not reveal the existence of bed rock, and throw comparatively little light on underground conditions. If the consolidated sandstone and shale beds continue to form the core of the dike in this direction, they lie deeper than the drill has yet reached. But the dike is none the less efficient as a dam, and even in those areas where the only surface outcrops are unconsolidated gravels a comparison of the water levels above and below its line indicates that clays or other impervious materials must form its axis. Folds of this character in beds which are very recent are not at all unusual in this part of the State, and they have an important and significant relation to several of the most prominent artesian areas. The San Bernardino artesian belt, for example, is limited on the downstream side by the Bunker Hill "dike," an anticline in late clays very similar to that which extends eastward from Raymond Hill. The great coastal-plain basin also is limited on its seaward side by a broad broken ridge, which is the surface expression of a gentle arch in the coastal-plain sediments.

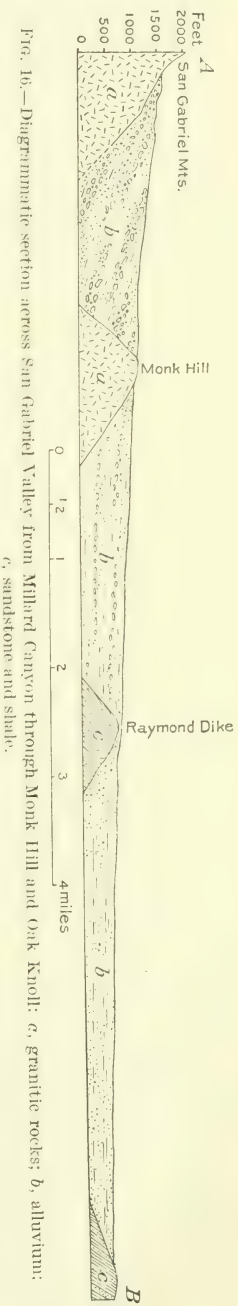

FIG. 16.—Diagrammatic section across San Gabriel Valley from Millard Canyon through Monk Hill and Oak Knoll: *a*, granitic rocks; *b*, alluvium; *c*, sandstone and shale.

All these gentle anticlines are very late features, geologically, and are most important factors in the storage and development of California ground waters.

FLUCTUATIONS IN GROUND-WATER LEVELS.

EVIDENT EFFECTS.

It is probable that ground-water levels in the basins of southern California were highest in the early nineties, at the end of the decade of heavy rainfall which included the exceptional seasons of 1883–84, 1885–86, 1889–90, and 1892–93. The recurring wet winters of this period and the fact that at that time comparatively little development of underground waters had been undertaken, so that there was practically no artificial drainage, were favorable conditions for raising the saturation level of the sands and gravels.

The southern California artesian areas occur in the subterranean basins wherever a favorable alternation of coarse and fine material, a sufficient water supply, and a barrier against which the waters can accumulate are found together. These favoring circumstances are to be sought along the lower edge of the various basins, nearly all of which contain areas that yield such flowing waters. The greatest combined area of the artesian water-bearing lands in southern California was 375 square miles, and while a very definite date can not be fixed for this maximum, it probably occurred in the early nineties. By 1904 there had been a contraction of one-third—to 250 square miles. Much of this contraction was due to the lessened rainfall of the last six or seven years of the nineties, but inasmuch as, in some of the basins at least, shrinkage continued during the four years following 1900, when the rainfall throughout southern California was about equal to the average, this shrinkage must be attributed in part to drainage of the reservoirs by pumping plants and artesian wells.

Ground-water levels in the various basins offer better evidence than changes in artesian areas as to the effect of drought and development on the level of the plane of saturation. For certain areas outside of the foothill belt such evidence of this character as is available has been discussed in preceding reports.[a] It may be stated here, however, that records kept by Mr. Neff, near Anaheim, indicate that in that particular region the underground waters are being drawn out by the numerous pumping plants more rapidly than they are restored by natural processes during years of more than average rainfall. A similar conclusion is forced on the student

[a] Water-Sup. and Irr. Papers Nos. 137, 138, 139, and 142, U. S. Geol. Survey, 1905.

of conditions in the San Bernardino Valley, where the artesian basin is smaller and somewhat more complete records are available.[a]

In the foothill belt no long-continued observations of ground-water levels have been made. A series of such observations has been begun by the United States Geological Survey, and in time they will furnish accurate criteria from which to judge the effects of the intensive development which the favorable character of the citrus lands there has induced. As yet no far-reaching conclusions can be drawn from them, but such evidence as they present will be discussed.

Although in this area continuous measurements on ground-water levels are not to be had, certain important facts in the history of the artesian belts are available. In the first place it needs to be reiterated that various parts of the foothill belt constitute separate and independent water basins, and that the fluctuation of the ground-water levels in each of these basins depends on local rainfall or contributing local run-off and local developments, and is not necessarily similar to the fluctuation in an adjacent area. Thus the Cucamonga Plains east of the San Jose Hills are to be regarded as one province, San Dimas Wash as another, the lower San Gabriel basin about Elmonte and Bassett as another, the North Pasadena Basin above Devils Gate as another, and the lower Pasadena Basin above the Raymond Hill "dike" as still another. The developments in some of these basins may affect the supply somewhat in others, but this effect is on the whole slight. For instance, excess waters from both the Pasadena basins and from San Dimas Wash have always drained toward the Elmonte basin, and have made small contributions to the supply there, but inasmuch as far the greater part of this supply comes directly from San Gabriel Canyon, the effect on the Elmonte water levels of developments at Devils Gate or San Dimas is negligible. A more pronounced effect of this sort is to be observed in the result in the San Jose Valley of developments in the old Palomares ciénaga above Pomona. At a time preceding the settlement of the valley San Jose Creek was a summer stream, fed by the waters which rose as springs in this ciénaga. After the settlement these waters were diverted for irrigation, and San Jose Valley was thus deprived of a part of its normal supply. Similarly all developments in the San Dimas pass about Lordsburg probably affect in a small but indeterminable measure the ground-water supply east and west of that locality, in areas toward which these waters would drain if not disturbed. All of these effects are in part, and some, perhaps, are wholly, neutralized by the return waters which seep down from the irrigated lands.

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[a] Water-Sup. and Irr. Paper No. 142, U. S. Geol. Survey, 1905, pp. 56–67.

The principal original artesian areas of the foothill belt were the Pasadena Basin, a long, narrow area just above the Raymond "dike;" the area 3 miles south of San Gabriel, in which were three or four weak flowing wells; the Palomares ciénaga, above the eastern point of the San Jose Hills; the Del Monte and Martin ciénagas, near Claremont, and the "east" and "west" ciénagas, in the Red Hills. Water rises to the surface naturally in but two of these areas at present; in the others a heavy lift is required to bring it out to the level of the heads of the ditches. The effect of development and drought here is even more pronounced than that observed in the coastal plain or the San Bernardino Valley, where continuous measurements of the decline in ground-water levels indicate that drafts at present are excessive. In the Palomares ciénaga water rose to the surface as late as 1900 in some of the stronger wells, and much artesian water was available there two or three years before this date. In 1905 the ground-water level in the heart of the old area of flow was 35 feet or 40 feet below the surface, and in some of the wells which were once artesian the water stood 60 or 70 feet below the surface. Tunnels at 50 to 100 feet below the surface now tap the waters of the East and West ciénagas in the Red Hills district, and the gravity flow, even at these levels, is small.

MEASUREMENTS.

In order to obtain definite data on these phenomena of changing water levels the United States Geological Survey has selected a number of wells in various localities for regular measurement.

WELLS NEAR POMONA.

In the vicinity of Pomona two wells thus selected belong to the Gird group near the east end of the old Palomares ciénaga. The measurements thus far made are given below.

Measurements of fluctuation of water level in wells near east end of old Palomares ciénaga.

Date.	Depth to water. Well No. 284.		Depth to water. Well No. 299.	
	Ft.	*in.*	*Ft.*	*in.*
1904.				
September 7	75	2	76	2
October 6	75	4½	77	2
November 16	74	6	76	5½
December 13	74	3	76	2½
1905.				
January 11	68	10½	70	5½
February 20	66	1	67	8½
March 16	65	11	67	5½
April 14	63	11	65	7½
May 17	62	11	64	5
June 22	66	8	68	2
July 20	70	10	72	8
1905—Continued.				
August 16	71	11	73	9
September 21	73	5	75	3
November 11	70	4½	71	5
December 20	67		68	8
1906.				
January 26	64	9	68	6
March 14	62	10	67	4
May 8	62	5	62	½
June 26	64	5	65	10
August 1	67		68	1
September 24	67	½	68	3
December 10	64	3½	65	8

These two wells are near together and their measurements are very similar throughout. Each shows a gain between the September measurements of 1904 and 1905, and a more pronounced gain when the water level in September, 1906, is compared with that of September, 1905. The period spanned by the measurements includes only two high-water dates—May, 1905, and May, 1906—and a slight gain is indicated at the later period, the gain being more pronounced in well No. 299 than in its neighbor. Well No. 284 is within 100 feet of one of the Gird wells which flowed until 1896. The sharp rise in the water plane in these wells between the measurements of December, 1904, and January, 1905, is probably to be attributed to the cessation of pumping in the vicinity at this time; and the almost equally sharp fall between the May and June measurements of the following spring marks the vigorous opening of the summer pumping season. If any two dates a year apart are selected in the table, it is seen that the water level has risen by amounts ranging from a few inches to as much as 7 feet in the interval, so that in this part of the basin the heavy rainfall of 1904–5 and 1905–6 has resulted in a marked improvement in conditions. As the water level fell at an average rate of 7 to 8 feet per year during the decade from 1896 to 1906, improvement is welcomed.

A well near the western edge of Pomona, owned by B. Linnastruth (No. 12, Pomona quadrangle), has been measured since December 19, 1904. The results are as follows:

Measurements of fluctuation of water level in Linnastruth well, near Pomona.

Date.	Depth to water.		Date.	Depth to water.	
	Ft.	*in.*		*Ft.*	*in.*
1904.			1905—Continued.		
December 14	90	6½	November 12	93	4
			December 21	93	6
1905.			1906.		
January 12	90	9	March 15	92	6
February 21	91	1	May 9	94	6
April 15	91	5	June 27	93	6
May 17	91	6½	August 2	95	6
June 22	92		September 25	96	
July 21	92	10½	December 11	95	2
September 23	93	6			

This well is unfavorably situated, in that it lies below the majority of the strong pumping plants of the Pomona neighborhood and away from the storm-water channels, so that it gets the full adverse effect of heavy pumping and but little of the beneficial effect of the flow in the flood channels. The result is that there has been an almost uniform slow decline since the beginning of measurements; the water plane in December, 1906, being 4 feet 7½ inches lower than in December, 1904. During only four of the thirteen intervals between measurements was there any recovery whatever, and the greatest of

these, which took place between the May and June measurements, 1906, registers an improvement of only 1 foot.

WELLS NEAR SAN DIMAS.

In the years following 1896 San Dimas Wash attracted attention because of the ease with which water could be developed in it, and because of its elevation, which made it possible to conduct the water by gravity to the citrus lands in the Glendora and Covina neighborhoods. In 1896, when the first plant was installed by J. O. Enell, the ground-water level was within 44 feet of the surface; but with the continued installation of plants and continuous pumping during the dry years the water plane was drawn down to about 135 feet in 1905, and when all the pumping plants are operating, it may be temporarily lowered below 200 feet in this immediate vicinity. Details of this decline are not available. United States Geological Survey measurements have been maintained about two years, and they indicate that during that time there has been a gratifying improvement in conditions in the wash, due directly to the increased rainfall within the San Dimas watershed and the consequent added quantity of water which has been absorbed by the gravels there, and to the increase in gravity waters in other near-by canyons. Since many of the irrigating systems use pumped water only to augment their gravity supply, this increase has greatly reduced the drafts on the San Dimas basin by the pumping plants established there.

One of the wells selected for measurement (No. 246, Pomona quadrangle), belongs to E. Firth, and is situated half a mile west of the principal group of pumping stations and about 50 feet below them. It is far enough away from them not to be greatly affected by the fluctuations due to the starting and stopping of pumps, and so records the general rise and fall of the ground-water level. The record is as follows:

Measurements of fluctuation of water level in Firth well.

Date.	Depth to water.		Date.	Depth to water.	
1904.	*Ft.*	*in.*	1905—Continued.	*Ft.*	*in.*
September 7	110	6½	August 16	105	10
October 7	111	7	September 21	106	7½
November 16	113	2	November 11	108	1½
December 13	113	11	December 20	109	1
1905.			1906.		
January 11	114	8½	January 27	107	6½
February 20	113	11	March 15	108	2
March 11	113	7	May 8	87	10
April 14	106	10	June 26	92	11
May 17	104	9	August 1	[a] 114	5
June 22	104	4	September 24	97	4½
July 20	105	6	December 10	96	11

[a] Pumping.

A comparison of September measurements in this well indicates a gain of 4 feet between 1904 and 1905, and a gain of over 9 feet between 1905 and 1906, or a total of 13 feet for the two years. The lowest period following the summer of 1904, however, was not reached until January, 1905, and that of the succeeding season came in December. A comparison of these two dates indicates a gain of somewhat more than 5½ feet in the interval.

If we accept the September measurements of 1904 and 1906, with their recorded recovery of 13 feet, as indicating fairly the improvement in conditions during these two years of heavy rainfall, and regard the decline between 1896 and 1904 as aggregating about 65 feet, the greater part of which took place in the latter part of the interval, we reach the conclusion that ten years of rainfall as heavy as that of the last two seasons will restore the underground waters to their original level. Even during these two years of heavy rainfall, however, not all wells in the vicinity exhibit so marked a recovery, as is evident from the following record of the Azusa Irrigating Company's well (No. 251, Pomona quadrangle):

Measurements of fluctuations of water level in Azusa Irrigating Company's well.

Date.	Depth to water.		Date.	Depth to water.	
1904.	*Ft.*	*in.*	1905—Continued.	*Ft.*	*in.*
October 7	97	2	September 21	97	4
November 16	97	8	November 11	98	6
December 13	98	11	December 20	99	
1905.			1906.		
January 11	99	1	January 27	97	10
February 20	98	4	March 15	97	2
March 11	97	4	May 8	93	2
April 14	95	6	June 26	91	1½
May 17	94	3	August 1	92	4
June 22	94	1	September 24	98	7½
July 20	95	4	December 10	100	11
August 16	96	4			

This well is about one-half mile southwest of the Firth well, is farther from the storm-water channel and from the big pumping plants, and is consequently expected to exhibit less marked fluctuations. There was but 1 inch difference between the low-water periods following the summers of 1904 and 1905; but the low-water period of 1906 is 1 foot 11 inches below that of the preceding fall. The September measurement in 1906 shows a loss over that of 1905, and the latter a slight loss over the October measurement of 1904. The high-water period of June, 1906, however, shows a recovery of 3 feet as compared with that of June, 1905. There is a slight net loss in the two years of observations, but as measurements are made at considerable intervals, with a resulting improbability that either the highest or the lowest water periods are detected, it may be said in a general way that this well is just about holding its own.

Two other observation wells (Nos. 144 and 149, Pomona quadrangle), belonging respectively to William Ferry and Sidney Deacon and located 1½ to 2 miles southwest of San Dimas, show somewhat different results. Their record is given below.

Measurements of fluctuations of water level in wells near San Dimas.

Date.	Depth to water. Well No. 144.		Depth to water. Well No. 149.	
	Ft.	*in.*	*Ft.*	*in.*
1904.				
October 7	199	8	124	3
November 16	199	10	124	
December 13	199	10½	124	
1905.				
January 11	199	9½	123	6
February 21	199	8	123	5
March 10	199	8½	127	
April 14	200	4	125	8
May 17	.....		124	8
June 22	200	4½	125	1½
July 23	200	6	125	5
August 16	200	7	125	5
1905—Continued.				
September 21	200	7	125	7
November 11	201		126	
December 20	201		.....	
1906.				
January 27	201	3	124	6
March 15	201	3	124	3
May 8	201	2	.....	
June 26	201	5½	124	6
August 2	201	9	.....	
September 24	201	7½	.....	
December 10	202	4	.....	

The water levels in these wells exhibit but little variation, but such changes as have taken place have been in the direction of loss, the fall measurements of 1905 and 1906 being in each case about 1 foot lower than those of the preceding year. In the Deacon well (No. 149) the fall measurements for 1906 were interfered with by an abnormal rise, probably due to the inflow of surface water; but the 1905 measurements indicate a loss as compared with those of 1904, and the high-water measurements one year apart indicate the same condition. Both of these wells are some distance from any of the washes through which the ground waters are replenished; therefore they exhibit but slight monthly and annual fluctuations. The slow wave of percolating waters, which starts from the washes in all directions through the gravels, with each winter's floods, is very flat indeed before it reaches these more distant wells. Its maximum height in the Ferry well was 2½ inches, reached in February, 1905. In the Deacon well this crest was 10 inches above the low level reached during the previous October.

WELLS NEAR VINELAND.

Two wells at Vineland, near San Gabriel Wash, show this wave of percolating water much more strongly developed. In a case of this kind, where the annual fluctuations are violent, long records are necessary before accurate conclusions can be drawn. In such short records as we now have, general movements of the water plane up or down are obscured by the great range of the seasonal fluctuations. On the face of these records, however, a distinct net gain is observed.

Measurements of fluctuations of water level in wells at Vineland.

Date.	Depth to water. Well No. 87.		Depth to water. Well No. 88.	
	Ft.	*in.*	*Ft.*	*in.*
1904.				
December 14	104	1	93	10
1905.				
January 12	104	6	93	6
February 21	102	10	91	5
March 10	98	9	87	6
April 15	93	11	82	7
May 17	90	8	78	10
June 22	90	11	79	4
July 21	91	4	79	10
August 16	92	2	81	4
September 20	93	9	82	10
1905—Continued.				
November 12	95	9	84	9
December 21	96	7	85	7
1906.				
January 27	97		86	
March 15	95	3	86	5
May 8	83	4	71	10
June 27	81	1½	70	3
August 1	82	11	69	
September 25	85	11	75	1½
December 11	88	10	78	7

The recovery in each of these wells for the two years of observation was 7 or 8 feet annually, with a net gain for the period of 15 feet 3 inches. Not only are the recoveries rapid and of great magnitude, but the annual fluctuations exhibit the wide range of 7 to 15 feet.

WELLS NEAR LORDSBURG.

Two record wells on the mesa northeast and northwest of Lordsburg, belonging to F. H. Massey and Charles Alley (Nos. 67 and 250, Pomona quadrangle), are measured regularly. They serve to record conditions on these valuable bench lands, where water developments have been extensive of late years.

Measurements of fluctuations of water level in wells on bench lands near Lordsburg.

Date.	Depth to water. Well No. 67.		Depth to water. Well No. 250.	
	Ft.	*in.*	*Ft.*	*in.*
1904.				
October 7			145	4
November 16	199	1	146	10
December 13	199	3	146	10
1905.				
January 11	19	11	146	9
February 20	199	10½	147	5½
March 11	199	9	147	6½
April 14	200		147	7
May 17	199	11	[a] 152	
June 22	199	4	146	8
July 20	200	2	150	8
August 16	199	9	150	½
1905—Continued.				
September 21	200		150	11
November 11	202	10	152	7
December 20	200	11	152	
1906.				
January 27	201	1	151	5½
March 15	200	2	149	2½
May 8	198	4½	149	6
June 26	197	6	149	½
August 1	196	5½	153	1½
September 24	197	7½	154	4½
December 10	197	3½	154	7

[a] Pumping.

The record of well No. 67 is rather erratic within narrow limits, probably because of variations in the pumping in its vicinity, yet general tendencies are discernible. A comparison of the water levels during the autumn months of 1904 with a corresponding period in 1905 indicates a slight loss of 1 to 3 feet, but when the 1905 and 1906 measurements are compared in the same way a distinct gain of 2½ to 5 feet is indicated, the net result for the two years being a recovery of 1 to 3 feet.

Well No. 250, over a mile farther northwest and near more large pumping plants, shows a decline in both the yearly periods. This decline amounted to 5 or 6 feet for the interval between November, 1904, and November, 1905, but was reduced to 2 or 3 feet for the interval from December, 1905, to December, 1906. The net loss in this well for the two years is 8 or 9 feet.

WELLS SOUTHEAST OF POMONA.

The group of four wells here discussed lies southeast of Pomona, toward the Chino artesian belt. In this direction the water plane and the land surface gradually approach, until in the artesian belt they practically coincide. This fact, as well as the fluctuations of the water table, is illustrated by the following measurements:

Measurements of fluctuations of water level in wells southeast of Pomona.

Date.	Depth to water.							
	Well No. 177.		Well No. 201.		Well No. 181.		Well No. 214.	
1904.	*Ft.*	*in.*	*Ft.*	*in.*	*Ft.*	*in.*	*Ft.*	*in.*
September 8	89		.....		34	6	8	9
October 6	88	10	58	9½	36	6½	6	6½
November 16	88	10½	60	3	34	10	3	10
December 13	88	10	60	6½	34	10	3	3
1905.								
January 11	88	10	60	10	34	9½	2	5
February 20	89		61	1½	34	7½	2	
March 10	89		61	4½	[a] 35	2	2	1½
April 14	88		60	8	32	10	1	5
May 17	.....		60	11	32	7	2	
June 22	88	11	61	1	33	6	7	5
July 20	90	1½	[a] 62	11	35	4	12	10
August 16	90	5	61	6	35		12	2
September 20	90	8½	61	10	35	6	11	10½
November 11	90	5	62	4	35	8	4	7½
December 20	90	6	62	5	35	7½	4	1
1906.								
January 26	89	6	62	3½	36	8½	4	3½
March 14	90	6	63	1	35	8	3	10
May 8	89	7	63	1½	33	2½	4	4½
June 26	.....		65	4	34	4½	13	10
August 1	92	2	63	5	35	5	15	8
September 24	92	2	64	4½	36	2½	13	6
December 10	.....		64	11	36	2½	4	10

[a] Pumping.

Each of the wells of this group shows a distinct though usually slight decline when corresponding dates one year apart are compared. One exception to this general condition appears in the October, 1904, measurement of well No. 181. No measurements were made in October, 1905, but the September and November measurements of that year indicate a higher water plane than on October 6, 1904. With this exception, however, the decline is general. The explanation is probably to be sought in the fact that all these wells lie below the Pomona dike, above which waters are so extensively pumped that but little of the surplus supplied by the heavy rains of 1904–5 and 1905–6 has escaped to this area farther south.

In addition to this general tendency toward shrinkage, exhibited by all of the wells, No. 214, very close to the edge of the artesian basin,

shows interesting annual fluctuations, which are probably due in part to the intense evaporation during the heated term, as well as to pumping in neighboring wells. From January to May, 1905, the water level in this well was but 1½ to 2½ feet below the land surface. From June to September of the same year it stood at 7 to 12 feet below the surface. During the heated term, in the dry atmosphere of this district, evaporation and capillarity act with great force, and draw the ground water from depths of several feet to discharge it as vapor into the air. This action is probably more effective in depressing the water table where it stood initially close to the surface than the drafts made in irrigation during the summer season.

WELLS NORTHEAST OF POMONA.

The four wells of which measurements are given in the subjoined table are located northeast of Pomona, two of them, Nos. 242 and 300, just south of the Santa Fe Railway tracks and three-fourths of a mile east of Claremont, and the other two, Nos. 265 and 265a, in the vicinity of Indian Hill. The buried ridge of red clays and gravels which extends eastward and northeastward from the point of the San Jose Hills, and whose extent beneath the gray gravels of the surface wash is, in a measure, problematical, introduces in the wells of this neighborhood an element of considerable uncertainty. One well may yield a good supply of water, while another near by, which happens to penetrate this older alluvium, will be dry; or the water level may stand at a certain elevation in one well and at a much lower or higher point in an adjacent well just across a buried ridge or "dike" of these dry gravels. There are many illustrations in the area northeast of Pomona of erratic conditions of this kind.

Measurements of fluctuations of water level in wells northeast of Pomona.

Date.	Depth to water.							
	Well No. 242.		Well No. 300.		Well No. 265.		Well No. 265a	
	Ft.	*in.*	*Ft.*	*in.*	*Ft.*	*in.*	*Ft.*	*in.*
1904.								
October 6	158	5	157	10	.....		.....	
November 16	156	2	154	3½	62	1	40	4½
December 13	155		153	2½	61	10	39	7
1905.								
January 11	153	1½	151	5	62	2	40	3½
February 20	151	1	149		62	1	40	1
March 10	150	2	147	10	61	10½	39	
April 14	148	7	146	7	59	4	37	6
May 17	147	1	145	1	59	1½	37	1
June 22	148	7	146	5	57	5	35	5
July 20	150	10	149	8	57		35	3
August 16	150	8	150	8	59	7	37	4
September 21	152	6½	151	4	58	6	38	3
November 11	152	1	156	8	58	4½	36	3
December 20	149	1	.....		57	3	35	7
1906.								
January 26	149	6	.....		56	9½	.....	
March 14	144	3	.....		53	2½	34	3
May 8	141	2	.....		54	4	32	6
June 26	132	4	.....		53	3½	31	6½
August 1	146	8	147		54	1	31	11½
September 24	149	8½	.....		53	3½	30	6½
December 10	149	8	.....		56	10	33	10½

This group, lying for the most part above the Pomona dike, contrasts in a marked way with the group last discussed, which lies entirely below it. The three wells in which continuous measurements have been maintained for two years all show substantial recoveries; but, curiously enough, the recoveries were more marked during the first than during the second of the two years. There seems to have been no cumulative effect, such as some other wells exhibit, in consequence of the two successive years of heavy rainfall. The net recoveries for the period from December, 1904, to December, 1906, amount to 5 or 6 feet in each well.

WELLS IN SAN GABRIEL RIVER BASIN.

The group of five wells here discussed lies west of the San Gabriel River in the lower part of the San Gabriel basin. The wells are arranged in the table in the order of their distance from the river, which is the principal source of the water by which the recharge of the basin is effected. In considering these measurements it is well to remember that the lower San Gabriel basin has one of the best supplies of underground water in this part of the State, and that it has not been too heavily drawn upon, as is true of many other moist-land areas. The water plane, therefore, was not depressed excessively during the dry period. Seasonal fluctuations normally are not as great in the Elmonte region as at points like Vineland, higher up on an alluvial fan, but are greater than at places lower down, as in the Paso de Bartolo, for example. The recovery which these wells exhibit is regarded rather as a return of the waters to their normal levels, and an elimination of the effects of drought, than as a replacement of waters withdrawn by development.

The magnitude of the seasonal variations and the amount of the net gain shown in these wells decrease with the distance from San Gabriel River. The net improvement, only the December measurements two years apart being considered, varies from 10 inches in well No. 476 to 7 feet 9 inches in well No. 164, and the range of annual fluctuations from about 3 feet to 6 or 8 feet.

In only one of the numerous canals heading in or just above the Paso de Bartolo and depending on the waters that rise there has it been necessary to install pumping machinery to keep up the supply during the dry years through which the country has passed, and unless there are further extensive developments above the pass the supply to these canals, which now receive gravity water, should remain sufficient. It is indeed possible that considerable amounts of water could be withdrawn from the Elmonte field by pumping without interfering with the supply below, because a slight lowering of the water plane, where it stands very near the surface, would lessen the loss by evaporation from these moist lands during the

summer months, and the water thus saved would become available for irrigation. It can be saved only by pumping and so depressing the surface of saturation.

Measurements of fluctuations of water level in wells in lower part of San Gabriel basin.

Date.	Depth to water.									
	Well No. 164.		Well No. 478.		Well No. 141.		Well No. 476.		Well No. 107.	
1904.	*Ft.*	*in.*	*Ft.*	*in.*	*Ft.*	*in.*	*Ft.*	*in.*	*Ft.*	*in.*
November 8	.....		22	5	.....		21	3	.....	
December 9	21	5½	22	6½	16	2	19	6	72	11
1905.										
January 4	21	5	22	6	16	1½	20	1½	72	10
February 9	20	8	21	9	16	3	20	0	73	0
March 17	17	10	20	1	13	8	19	3	72	10
April 12	15	10	18	1	13	2	18	4	72	7
May 10	14	8	16	8	14	8	17	8	[a] 74	6
June 13	13	8	16	11	14	6	18	7	73	4
July 12	13	9	17	5	13	1	18	11	73	3
August 10	15	9	16	8	13	5½	19	2	74	1
September 13	16	10	17	5	14	4	20	0	[a] 75	8
November 7	17	3	18	2	14	1	20	3	.....	
December 18	17	0	18	0	13	9	21	3	73	0
1906.										
January 24	17	4	18	9½	13	8½	19	10	76	2½
March 22	15	4	17	3	12	6	18	11	72	8½
May 5	12	8	14	4	11	8	18	1	72	7½
June 25	11	9	12	9½	11	5	18	4	72	8
July 31	12	2	12	11½	11	10½	18	8	72	3½
September 20	13	5½	14	1	12	2½	19	6	72	1
December 17	13	8	14	7½	11	9	18	8	71	4

[a] Pumping.

WELLS IN PASADENA BASIN.

The wells of the next group are in the Pasadena basin above the Raymond Hill dike. They are in a region in which there is relatively little annual fluctuation, because it is far from the regular flood channels and receives its general supply only after it has percolated long distances through the gravels. The well of the group which exhibits the annual pulsations most clearly is No. 40a, on the Titus ranch at Sunny Slope. This well is in the old artesian basin, and the annual variations of its water level are probably due, in part at least, to summer evaporation, as in the well above Chino. While the record of this well is short and somewhat broken, it seems to indicate a slight gain. The record of No. 474 is also imperfect, but indicates an improvement in conditions. On the other hand, Nos. 56 and 17 indicate slight net losses for the period spanned by the measurements, although a gain of 2 inches appears for the last year of the period in No. 17.

Measurements of fluctuations of water level in wells in Pasadena basin.

Date.	Depth to water.							
	Well No. 474.		Well No. 40a.		Well No. 56.		Well No. 17.	
	Ft.	*in.*	*Ft.*	*in.*	*Ft.*	*in.*	*Ft.*	*in.*
1904.								
September 2	44	3			73	3	122	4
October 5	44	10			73	10	122	2½
November 8	44	0			73	11	122	7
December 19	45	1½	13	6	74	6	122	6½
1905.								
January 4	43	6	10	4½	74	6	121	1
February 9	43	1	8	7	74	4	122	2
March 17	43	0	8	6			122	2
April 12	39	11	7	8	73	8	122	2
May 10	39	4	8	1	73	5	122	1
June 13			11	6	73	5	122	4
July 12	41	9	16	1	74	0	123	3
August 10			19	2	74	5	123	5
September 13			16	2	75	0	124	0
November 7			12	10	75	0	124	1
December 18			10	7	75	9	123	7
1906.								
January 24	41	5	10	3			123	3½
March 22	41	0	10	0	74	6	123	2½
May 5			8	4	74	9	122	11
June 25					74	6	122	8
July 10	41	2						
July 31			18	3	75	3½	123	6½
September 20			16	9½	76	1½	123	10
December 17			14	4½	77	1	123	1½

SUMMARY OF RESULTS OF WATER-PLANE MEASUREMENTS.

The wells which have been selected for measurement within the foothill belt are distributed widely over it. They include those favorably situated in relation to pumped areas and flood channels and those less favorably situated. They represent the greater number of the important local basins, and are probably to be depended on to indicate general conditions fairly. Measurements of 28 of these wells have been given in the tables. Fifteen of these show a net gain for the two-year period and 10 show a net loss, while 3 are indeterminate because of incomplete measurements. The year from September, 1905, to September, 1906, was more effective than the preceding year in restoring water levels, as is illustrated by the fact that 16 wells showed net gains for 1906, while net losses are registered in 10, 2 being indeterminate; whereas only 14 register a gain in water levels in 1905, and an equal number show losses. The gains, as has been indicated, are in wells situated close to drainage lines, and the losses in wells farther away from them. Fortunately the pumping plants of the more important systems are thus favorably situated, and a majority of them are gainers by the partial restoration of water levels which has taken place within the past two years. A smaller number are not within the belts that are thus favorably situated.

On the whole, while there has been a definite improvement in conditions in some of the basins during the period of observations—a period of marked excess in rainfall—the fact that water levels have

continued to decline steadily in others, when conditions are so favorable for recovery, indicates excessive drafts in these latter localities at least. The general conclusion reached two years ago, that there are serious overdrafts on the ground water-basins, seems to be supported fully by the more abundant evidence now available.

IRRIGATION ENTERPRISES.

INTRODUCTION.

In 1888 Wm. Ham. Hall, State engineer of California, published his volume on "Irrigation in Southern California." This work included an account of the organization and engineering features of practically all the irrigation enterprises in existence in the southern part of the State at that time. The work has been extremely useful to all who have desired to gain a general idea of irrigation development in this part of the State. In the foothill belt many enterprises have been organized since the publication of Hall's work, and the conditions under which some of the older ones operate have been altered by reorganization and otherwise. Especially important have been the development of ground waters and the organization of companies for this purpose, or the extension of the functions of older gravity companies to enable them to utilize ground waters.

It has seemed worth while to present with this volume an account of the more important irrigating companies now operating in the foothill belt. For the earlier history of those enterprises which had been organized before 1888, Hall's volume has been consulted. For developments since, including the organization of new companies as well as changes in the older ones, various sources of information have been utilized, but in the majority of cases officers of the companies themselves have been consulted.

In the collection of this material the writer desires to acknowledge his indebtedness to Mr. W. N. White, field assistant, who gathered much the greater part of the information. Acknowledgments are due also to many engineers, not all of whom it is possible to mention. Mr. T. D. Allin and Mr. E. T. Wright have been consulted especially.

In presenting this material the plan followed has been to discuss the companies in the order of their distribution from east to west along the foothill belt. Those first described, therefore, are the Cucamonga enterprises, and those last described are the companies operating in Verdugo Canyon.

ETIWANDA WATER COMPANY.

The Etiwanda Water Company controls the waters of Day and Etiwanda canyons and utilizes these waters in the irrigation of about 1,200 acres of the Etiwanda colony lands, lying from 1½ to 4 miles north of the Santa Fe Railway at West Etiwanda station. The

rights of the company date back to a number of filings by George Day and others from 1867 to 1873. These rights were afterwards consolidated, passed through several transfers, and have been confirmed in a number of suits.

The present company was organized by George and W. B. Chaffey in 1882. It is capitalized at $500,000, divided into 5,000 shares at a par value of $100 each; 2,300 shares have been issued, and the present market value is reported to be about $35 per share. The shares are not appurtenant to the land, but 90 per cent of them are held by irrigators, of whom there are about 75 in the colony.

As the colony lands were originally sold, one share of stock in the water company was transferred with each acre of land, and each 8 shares of stock entitled the owner to 1 miner's inch of water. It is customary to deliver the water monthly in 36-inch heads to each 10-acre tract, this giving approximately the usual duty of 1 inch to 8 acres, at a cost to the irrigators of $1.45 per acre annually.

The water is brought from the canyons through 1½ miles of V-shaped wooden flume and 2 miles of 10 and 12 inch pipe to a distributing box at the head of the colony lands. Below the distributing box are about 20 miles of 7 to 10 inch pipe, through which the water is conducted to the individual holdings. The reported cost of the pipe system is $23,000. There are no auxiliary wells, as in the case of many modern irrigation systems in southern California, ground waters beneath the Etiwanda district being too deep for profitable development.

Citrus fruits and grapes are the principal crops grown.

Only a few measurements of the flow from Day and Etiwanda canyons are available. These are quoted from "Irrigation in Southern California," by Wm. Ham. Hall.

Flow measurements in Day and Etiwanda canyons.

	Miner's inches.
September 1, 1882	224.5
July 15, 1884 (noon)	211
July 15, 1885 (7 a. m.)	170
August, 1885	50
July 15, 1887	189
July 15, 1888	[a] 356
July 16, 1888	[b] 421.31
August, 1888	150

HERMOSA WATER COMPANY.

The next important irrigating enterprise along the foothills west of Etiwanda is that of the Hermosa Water Company. Lying along the slope, 3 miles from Etiwanda and about 1 mile north of Cucamonga,

[a] 28 miner's inches considered as developed water.
[b] Calculated from slope and section of flume.

the Hermosa tract originally embraced 480 acres of land, upon which the waters of Deer Canyon and its tributaries are used.

The Hermosa Water Company was organized by owners of realty who had purchased lands and undivided interests in the waters of Deer Canyon from Adolph Petch or from the Hermosa Land and Water Company, organized by Petch in 1882. The water company was incorporated in October, 1887, with a capital stock of $192,000, divided into 1,920 shares with a par value of $100 per share. Four shares of stock were issued to each acre of the original tract, and each owner received a share of the available water proportional to his holdings of stock and acreage.

For many years the canyon flow was sufficient for the needs of the colony, but after the dry years of the late nineties the supply from the mountains so diminished in volume that it became necessary to augment it from some other source. In 1901 the company purchased 80 acres of land from the Cucamonga homestead, one-half mile north and west of the Hermosa tract, sunk a well on this property, and installed a pumping plant (No. 56, Cucamonga quadrangle).

The water from Deer Canyon and its branches, Calamity and Hermosa canyons, is collected by means of about 4 miles of 2-, 3-, and 4-inch pipe, and carried out of the canyon and down the slope, a distance of nearly 4 miles, through an 8-inch cement main, to a reservoir at the head of the colony lands. Just below the mouth of the canyon a branch pipe from Alder Canyon joins the main line. The company is entitled to the water of Alder Canyon up to 20 miner's inches. The upper part of the main-canyon conduit, which was originally an open flume, has been replaced by an 18-inch cement pipe. Delivery from the reservoir to the lands of the irrigators is made through 4- and 8-inch pipe.

The summer flow from Deer Canyon and its branches varies with the rainfall of the previous winter. The company reports that in July, 1903, it received 70 inches of mountain water, an average of 45 inches through the irrigating season of 1904, and 80 inches in August, 1905. Pumped water is used as an auxiliary to the canyon flow. During the season of 1902 the plant, consisting of a 20-horsepower gas engine and Ames Fulton pump with a capacity of 30 miner's inches, was in operation one hundred and forty days consecutively. During the season of 1903, following a wet winter, the flow from the canyon supplied the needs of the company and the pumping plant was not used. Again during the summer of 1904 mountain water was short in quantity, and pumped water was used freely in making up the deficiency.

The water supply is divided into heads and distributed to the irrigators in rotation every twenty-four days. The time given to each irrigator varies with his holdings of stock. A man owning 40

shares is given twenty-four hours' run of a half head every twenty-four days.

The cost of operating and maintaining the system is prorated among the stockholders according to the proportion of stock held by each, the annual cost of water varying with the volume of pumped water used. The actual cost of pumping a 30-inch head for twenty-four hours is $5.25 under present conditions. The only expense attached to the delivery of canyon water is the cost of keeping the pipe lines in repair, the secretary's annual salary of $50, and the zanjero's fees. The average cost of all water used, gravity and pumped, during the past four seasons, is reported to have been $5.75 per acre per annum. There are 40 irrigators in the colony, and at the present time about 500 acres are supplied with water. The company owns 1,200 acres of land in Deer and Calamity canyons, which were homesteaded by stockholders and deeded to the company in order to protect its water rights there.

The company's investment is as follows: Pumping-plant site, 80 acres, $4,900; reservoir site, 2½ acres, $125; pipe system and reservoir $4,000; well and pumping plant, $3,300; total, $12,325.

The right to use the water for power purposes, reserved by the promoters at the time the land and water rights were sold, is now held by the company.

IOAMOSA WATER COMPANY.

The Ioamosa tract, in which there are 500 acres of irrigated land, lies about 1 mile north and west of the Hermosa colony. The lands are a part of the old Cucamonga Homestead Association's property, and the water with which they are supplied comes entirely from Cucamonga Canyon and belongs in part to the Cucamonga Development Company.

The Ioamosa Water Company was incorporated in 1883, with a capitalization of $50,000, divided into 500 shares, with a par value of $100 per share. The company holds title to $\frac{86}{300}$ of the surface and developed flow of Cucamonga Canyon and leases the balance of all water derived from that source from the Cucamonga Development Company at a yearly rental of $500. The water procured by diversion of the surface flow and by 700 feet of tunnel intended to intercept the underflow is brought to the mouth of the canyon through a 30-inch conduit 3,400 feet long. Thence it is taken diagonally across the slope in a southeasterly direction in a 12- and 8-inch cement line to a small reservoir at the upper end of the colony lands. Below the reservoir about 2 miles of 8-inch vitrified and 6-inch iron pipe have been laid for delivering the water to the irrigators.

It is reported that from 10 to 40 inches are developed in the tunnel, while the total flow, natural and developed, is said to vary from 30

to 100 inches. The duty of water in the colony is reputed to be 1 miner's inch for each 7½ acres, distributed in two 40-inch heads, twice each month to each 20-acre lot. Twenty-three irrigators are supplied, and the cost of water is about $2 per acre per year.

CUCAMONGA LANDS AND CUCAMONGA WATER COMPANY.

What are known as the Cucamonga lands are situated in the western portion of San Bernardino County, between the San Bernardino base line and the Southern Pacific Railroad, which is about 4 miles distant on the south. They extend eastward about 4 miles from the Ontario colony lands and Cucamonga Wash, and include in the aggregate between 8,000 and 9,000 acres, about one-third of which is irrigated, while another one-third is cultivated as vineyard but is not under irrigation.

The well-known Red Hills, famous as water-bearing lands, lie in the northwest corner of the Cucamonga tract, and the developments in and adjacent to these hills supply the water used for irrigation in the Cucamonga district and a portion of that used farther west by the San Antonio system.

The Cucamonga Water Company, which at present supplies nearly all of the water used in the district, was incorporated in December 1887, by certain members of an older organization called the Cucamonga Fruit Land Company. This company owned all the waters flowing from the "West ciénaga," the moist lands west and north of the Red Hills, and one-half of the waters flowing from the "East ciénaga," a similar area lying in and northeast of the Red Hills. At that time the total amount of water thus owned was between 250 and 300 miner's inches. The other half of the east-side waters belonged to the Cucamonga Vineyard Association, and a total of about 400 acres was under irrigation by both organizations, the Vineyard Association being the heaviest water user.

In addition to these rights there were certain obligations outstanding against the Fruit Land Company. The "Class A" rights comprised 33.84 miner's inches due a certain group of "old settlers." The "Class B" rights comprised 67.75 miner's inches due another group of "old settlers," who had signed agreements to accept 1 miner's inch of water for each 10 acres of land owned by them. Other obligations constituting classes "C" and "D" were agreements to furnish water, by a company to be formed later, to lands which had been sold earlier by the Fruit Land Company. Something more than 300 inches was conveyed under these two classes.

All of the Fruit Land Company's rights to waters that were then flowing, all of its lands which were then recognized as water-bearing lands, and all of its obligations were conveyed to the Cucamonga Water Company at the time of its organization in 1887, and in

addition the older company contracted to develop and deliver to the purchasing company enough water to fulfill all of the obligations which had been conveyed with the rights in the deed.

In fulfillment of the terms of this contract, the Fruit Land Company, during the years 1888, 1889, and 1890, expended from $75,000 to $100,000 in developing water by sinking wells and driving tunnels, so that when measurements were made in July, 1890, it was found that about 500 inches of gravity water, in part natural flow and in part the result of the development work, belonged to the Cucamonga Water Company. This amount was more than enough to satisfy the rights outstanding at that time.

During the dry period which followed, the flow from these various sources decreased, until in 1899 only 190 inches of gravity water were available, and the water company was forced to augment its supply by pumping from the Lone Star Springs above the base line. During this year the Fruit Land Company bored a deep well on the lands which it still held on the west side but which, at the time of the transfer of its rights to the Cucamonga Water Company, had not been recognized nor classified as water-bearing lands and were therefore not included in the transfer. This well at first yielded 100 inches of water, and at about the time of its development the Fruit Land Company contracted to deliver to the San Antonio Water Company 100 inches of water for $100,000. Suit was brought by certain stockholders of the Cucamonga Water Company against both the Cucamonga Fruit Land Company and the San Antonio Water Company to prevent the consummation of the sale, but judgment was rendered in 1900 against them and the sale was confirmed. During the summer of 1900 the control of the Cucamonga Water Company passed into the hands of the stockholders who had brought this suit, through the purchase of outstanding stock, and they also bought of the Cucamonga Fruit Land Company an interest in all the lands still owned by that company that could be regarded as water bearing on the east and west sides of the Red Hills.

Since 1900 three or four wells have been put down, the tunnel has been extended, and a pumping plant known as the Lone Star system has been installed, so that stockholders have received their full quota of water, although gravity water has constantly decreased. This decrease has been particularly marked in the Y tunnel and in the creek near the old Cucamonga Hotel that drains the original East ciénaga. It is stated that the original supply from these sources was from 150 to 500 inches of water, and that now (1906) it is less than 5 inches. The Cucamonga Water Company regards this decrease as due to the battery of wells and pumps installed by the San Antonio Water Company north and west of

the Red Hills and used extensively as an adjunct to the San Antonio system. Suit has therefore been brought against the San Antonio Company to prevent pumping from these wells and to recover damages for property claimed to have been destroyed through this pumping. This suit was still in the courts in 1906.

When the Cucamonga Water Company was organized, in 1887, its capital was fixed at $100,000, divided into 10,000 shares at $10 per share. One share, representing one-tenth of a miner's inch of water continuous flow, was to be distributed with each acre of land sold. In 1901 or 1902, when a consolidation of interests was effected by the purchase of stock and rights owned by the Cucamonga Fruit Land Company and others, the capital stock was increased to $100 per share and bonds to the value of $250,000 were issued. Although the capitalization of the company was effected on the basis of 10,000 shares, the issue of stock has been controlled by the quantity of water available, not more than 10 shares being distributed for each inch of water owned, the amount of the water being determined by measurements made on July 15 of each year. The greatest amount of stock outstanding at any time was 4,500 shares, and this has been reduced by purchase to less than 3,000 shares.

In addition to the rights and lands which have been referred to, the company owns a number of tunnels, wells, and reservoirs, constructed generally by the Cucamonga Fruit Land Company in fulfillment of the contract entered into by it at the time of the organization of the Cucamonga Water Company. The west side or Eddy tunnel is one of these structures. It was originally a timbered tunnel, 3,600 feet long, but the timbering has been replaced by a 30-inch concrete pipe line. The charges for the maintenance of this line are shared with the San Antonio Water Company, which also uses it, the proportion of water in the tunnel belonging to each company determining the proportion of the running expenses borne by each. The east side or Y tunnel, just east of the old Cucamonga Hotel, also belongs to the Cucamonga Water Company, and, like the Eddy tunnel, has been replaced by a concrete pipe line. At the head of each arm of the Y is a well but since 1903 this work has yielded no water. A third tunnel, 3,000 feet in length and running northwest from the center of sec. 3, on Hellman avenue, extends through a 35-acre tract belonging to the Cucamonga Water Company and into the Lone Star tract. Eight or ten artesian wells discharge into this tunnel, but the greater part of the water which it yields is supplied by the upper well of the Lone Star group. In addition to these development works the company owns an adequate distributing system, which includes three reservoirs and 20 or 25 miles of iron pipe that serves all of the lands under irrigation.

All of the water distributed is delivered under pressure in 30-inch heads, each 10 shares of stock entitling the holder to a flow of 30 inches for one day in each month.

The fixed charges of the company, comprising the interest charges on the bond issue, amount to $15,000 annually. The maintenance charges amount to about $6,000 per year, and these expenses are met by annual assessments on the stock of $10 or less per share.

OLD SETTLERS WATER COMPANY.

The Old Settlers Water Company was organized by stockholders of the old Cucamonga Fruit Land Company, who held rights to 33.84 inches of the surface flow of the Red Hills East ciénaga. When this ciénaga ceased to flow, because of the dry years and the draft on the underflow caused by the tunnels and pumping plants in the vicinity, these irrigators found it necessary also to resort to pumping. With this purpose in view the present company was incorporated June 21, 1902, and capitalized at $33,840, divided into 33,840 shares of $1 par value each. Land was purchased three-fourths of a mile north of Cucamonga, a well was sunk, and a pumping plant, consisting of an 18-horsepower gas engine and an Addison deep-well pump, was installed (No. 53). This plant pumps about 33 inches of water. The distributing system consists of 1½ miles of 6-inch and 1 mile of 8-inch concrete and vitrified pipe. Two hundred and seventy acres are irrigated and the water is delivered in 33-inch heads in rotation, every thirty days, on the basis of 1 inch constant flow to 8 acres. The cost is $10 per acre per annum. The water is not appurtenant to the land, but stock is held exclusively by irrigators. Oranges and deciduous fruits are raised.

SUNSET WATER COMPANY.

The Sunset Water Company was incorporated January 10, 1901, with a capital stock of $60,000, divided into 2,400 shares, all of which have been issued. The company was organized by stockholders of the Cucamonga Water Company for the purpose of increasing their water supply. Thirty acres were purchased in the water-bearing lands northeast of the Red Hills, where a well was sunk and equipped with machinery for pumping. The pumping plant (No. 54, Cucamonga quadrangle) consists of a 14-horsepower motor and a Garrett pump, and has a capacity of 30 inches. The water is raised to the level of a discharge tunnel 30 feet below the ground level at the well, and brought to the surface through the tunnel, 1,000 feet below the plant. From this point the water is distributed to the lands of the irrigators through 3¼ miles of steel pipe 4 to 12 inches in diameter. In practice about 1 inch to 10 acres is used, though there is no restriction on the amount that may be used. Six hundred acres are

partially irrigated. The water is distributed in 30-inch heads monthly. The cost to the irrigators is $10 for a twenty-four-hour run of 30 inches. During the three seasons preceding the spring of 1904 the water level in the company's wells declined 4 to 6 feet annually, and with the lowering of the water plane the capacity of the plant has dropped from 42 to 30 inches. The plant is in operation about six months of each year.

ONTARIO COLONY AND SAN ANTONIO WATER COMPANY.

HISTORY OF RIGHTS.

The Ontario colony occupies lands lying immediately west of Cucamonga Wash and extending in a strip 1 to 3 miles wide from the mesa at the foot of the San Antonio Mountains down the slope for a distance of about 6 miles. On the west the upper part of the colony tract is separated from the Claremont and Pomona irrigating districts by San Antonio Wash, and the lower part of the tract adjoins lands that are covered by the Del Monte Irrigating Company of Pomona. On the east Cucamonga Wash lies between the colony lands and those of the Cucamonga irrigators.

About 5,000 acres are under irrigation in the Ontario district. Gravity water is supplied to the tract from San Antonio Canyon and from the Cucamonga tunnel in the water-bearing lands of the Red Hills, which lie to the east of the colony, midway between North Ontario and Cucamonga. The canyon and tunnel flow is supplemented by pumped water derived from wells north of the Red Hills on the east and from the neighborhood of Claremont and Indian Hill on the west.

By far the greater part of the water supplied to the colony is owned and distributed by the San Antonio Water Company. The Ontario Water Company is an adjunct organization, whose stockholders belong to the San Antonio Water Company but pump independently in case of a shortage. Several hundred acres lying west of North Ontario are supplied with pumped water by the plants of the Upland, Mountain View, and Canyon Ridge water companies.

The San Antonio Water Company is a mutual company, one of the early organizations of its kind in the State. Stockholders are owners of realty, and water can not be delivered by the company to others than stockholders. The company was incorporated in October, 1882, by the Messrs. Chaffee, who owned the water rights on the east side of San Antonio Canyon, and these rights, together with diversion works, conduits, and pipe system, were later transferred to the San Antonio Water Company. This company was organized with a capital stock of $1,500,000, divided into 15,000 shares of a par value of $100 each; 6,064 shares have been issued. In 1882, by agreement between the Chaffees and the Pomona Land and Water Company, which owned

water rights on the west side of the canyon, the surface flow at a point about 1 mile above the mouth of the canyon was divided equally, and a joint diversion dam was constructed. About 1896 the San Antonio Water Company acquired what was known as the Gird or Dexter interest in the canyon, consisting of several hundred acres of land, together with a prior right to 20 miner's inches of water. In 1897 the San Antonio Water Company and the Pomona Land and Water Company entered into an agreement by which the latter conveyed to the San Antonio Water Company all of its interests in the canyon, in return for which the San Antonio company agreed that whenever the total flow in the canyon was 624 inches or less the Pomona company was to receive one-half, and that all water in excess of 624 inches should belong to the San Antonio company. After entering into the above agreement the San Antonio company began to divert the 20 inches of Gird or Dexter water, piped it past the division dam, and continued this diversion for five years, when suit was brought by the Pomona Land and Water Company; but January 6, 1905, Judge Allen rendered a decision in which he held that the San Antonio company had acquired a good title to this water.

In 1902–3 the Ontario Power Company laid a conduit from the south line of sec. 36, T. 2 N., R. 8 W., diverted the canyon flow at that point, and piped the water along the west side of the canyon to a point on the hills above the division dam and constructed a power plant. This conduit is a 30-inch cement line, except where iron pipe is used in inverted siphons in crossing side canyons. It is laid partly in trenches and partly through tunnels. For a year previous to the laying of the conduit careful measurements were taken by expert hydraulic engineers at the south line of sec. 36 and at the division dam 3 miles below, and it was determined that 19 per cent of the water was lost from the natural flow of the canyon stream between the two points. After the completion of the conduit by which this loss was prevented, the Ontario Power Company laid claim to and appropriated 20 per cent of the flow of the canyon as salvage. This claim was subsequently disallowed by the courts, which ruled that the Pomona irrigators were entitled to one-half of the saving effected through the higher diversion of the Ontario Power Company.

It became apparent in the early days of the colony that there would not be sufficient surface water from San Antonio Canyon to supply all of its requirements, and steps were taken to procure additional water from other sources. In January, 1883, a tunnel was begun in the gravel bed of the canyon about 1 mile above its mouth; it was gradually extended during the succeeding years, and completed about 1889. This tunnel has a sectional area of 3½ by 6½ feet. It is 3,000 feet in length and is reported to have cost about $50,000. The upper 600 feet penetrates bed rock below the wash material of the creek, the

bottom at the upper extremity being 110 feet below the bed of the creek. F. E. Trask reported the average July output from this tunnel for 15 years previous to 1903 as 116 miner's inches. B. C. Shepherd, secretary of the company, states that the flow varies from 50 to 150 inches and averages about 75 inches during the irrigating season. The creek waters and the San Antonio tunnel waters are brought together in the main ditch about 500 feet below the mouth of the tunnel.

West of the Red Hills, in what is known as the West ciénaga, a tunnel 3,600 feet in length was constructed by the Cucamonga Fruit Land Company for the Cucamonga Water Company in the late eighties. This tunnel, which has since been extended to 4,000 feet or more in length, is known as the Eddy or Cucamonga tunnel. Some time after its construction the San Antonio Water Company acquired water-bearing lands in the West ciénaga, a 20-foot right of way, and one-half interest in the carrying capacity of the tunnel. In 1889 a 22-, 24-, and 30-inch cement pipe was laid from the division box at the mouth of the tunnel to North Ontario, and connected with the system there. Several wells were sunk along the upper course of the tunnel, and cut to flow into it at depths of 90 to 110 feet from the surface. It is known that one of these wells (No. 80, Cucamonga quadrangle) was flowing in 1905, and it is supposed that others were flowing then, but this could not be ascertained. The water from this tunnel, which belongs in part to the Cucamonga Water Company, is apportioned in a division box at the mouth of the tunnel, and is conducted thence to the distributing systems of the owning companies. Of the Ontario companes' share of the Cucamonga tunnel gravity water, the San Antonio Water Company receives the first 130 inches and the Ontario Power Company the balance. The average flow received by these two companies during the irrigating season has been reported as 150 miner's inches.

Previous to 1893 the canyon and tunnel water had been nearly sufficient for the needs of the colony. Beginning at about that time, several dry years followed in succession, causing a decline in the canyon flow and an extreme shortage of water. As the necessity for more water became pressing, the company sought relief through the further development of underground waters, which had been begun in a small way in the Del Monte ciénaga in 1889. Nine hundred and fifty acres of land were purchased east of the colony, north of Sixteenth street above the Cucamonga Red Hills, and in 1898 a well was sunk (No. 75, Cucamonga quadrangle), a pumping plant installed, and 16- and 20-inch vitrified pipe laid to connect with the canyon distributing system. At various times since then four additional plants have been installed on this property, the last in 1904. Water rights have also been acquired on the adjoining Rubio property, where

a plant has been installed, and still farther east two other wells, known as the Haskell wells, have been purchased and equipped with pumping plants.

In all, the San Antonio Water Company owns and operates eight plants (Nos. 73 79, Cucamonga quadrangle) in the Red Hills district, with a combined pumping capacity of 450 inches. The wells are seldom pumped to their full capacity, and the output varies with the needs of the colony and the fluctuations in the gravity flow from San Antonio Canyon and tunnel and the Cucamonga tunnel.

In addition to these more important Sixteenth street and Red Hills wells, the company has four wells, two of which are equipped with pumping plants, in the old Del Monte ciénaga, near Claremont. The output of the two wells pumped in this field is given as 75 miner's inches. In the operation of these wells, electric power supplied by the adjunct corporation, the Ontario Power Company, is used. This power succeeds the gas and steam engines which were used in the early pumping operations.

In 1898 the company acquired the Bodenhammer well (No. 88, Cucamonga quadrangle) and a tunnel located along the west line of the colony lands, about 1½ miles below the mouth of San Antonio Canyon. Since the well was sunk and the tunnel driven the water plane in this vicinity has dropped many feet below the tunnel level.

The San Antonio company also owns 1 mile of tunnel, which was driven into the mesa at the foot of the mountains just west of Cucamonga Wash. This work is reported to have cost $80,000. There is no summer yield during dry years, but in winter a moderate amount flows from the tunnel.

PIPE LINES AND CONDUITS.

The Ontario colony is piped throughout with carrying lines, constructed principally of cement and vitrified clay, and ranging from 8 to 40 inches in diameter. Distributing mains and diagonals have been laid in such a manner that the supply from the various sources can be readily shifted to different parts of the tract. Water in the pipes is not under pressure, but the onward flow is partially cut off by gates which hold the water and cause it to rise to the top of a short standpipe or turn-out, placed at the highest point of each 10-acre lot. Domestic water is carried from these turn-outs through iron pipes to the homes of the irrigators.

OPERATION AND MAINTENANCE.

Theoretically the San Antonio Water Company delivers 1 miner's inch of water to each 10 acres on each 10 shares of stock. In practice the available supply is prorated to the stock and a twenty-four-hour

run is given each 10 acres monthly, but the size of the irrigating head varies with the water supply, though the average is about 30 inches. During the irrigating season of 1905, succeeding a winter of excessive rainfall with a large canyon flow, the company expected to deliver 40-inch heads throughout the season.

ANNUAL COST.

The average cost of operating and maintaining the system of the San Antonio Water Company is $60,000 per annum, and the average cost per acre varies from $10 to $12. Funds for meeting obligations in the shape of interest, sinking fund, maintenance, and expenses are derived from assessments on the stock. A part of the floating indebtedness was paid off during 1904, and total assessments of $25 per acre were levied that year. Other payments were made in 1905, and an assessment of $20 per acre was collected.

ONTARIO WATER COMPANY.

The Ontario Water Company was organized in 1900 by stockholders of the San Antonio Water Company who did not hold enough stock in that company to insure them a sufficient water supply in years of light rainfall. The organization was effected on the basis of a capitalization of $100,000, divided into 1,000 shares with a par value of $100 each. In 1905 six hundred and twenty shares had been issued, 495 to irrigators and 125 to nonresidents, and the market value was reported by the company's officers to be $50 per share.

In 1900 a tract of 134 acres lying east and south of Indian Hill was purchased at a cost of $34,000. Six wells were at on cesunk on the tract and a pumping plant was installed, the expenditures for these purposes being $10,000. The plant consists of a 70-horsepower steam engine and a Smith-Vaile air compressor, by which all the wells which lie within a radius of 600 feet of the plant may be pumped. The water, about 70 miner's inches, is conducted through a 14-inch line about 3 miles in length to the tract owned by the stockholders. This tract lies about 1 mile southwest of Upland. As the water is used as an auxiliary to the canyon supply, it is necessary to pump only during the summer months, and not then if the flow from the canyon is large. The plant was in operation during four months in 1900, 1901, and 1902, but was not used in 1903.

The water is distributed in 30-inch heads and is prorated to stockholders according to their interest. The cost of the water is given at 67½ cents per hour for a 30-inch head; that is, 2¼ cents per hour-inch.

In order to carry out the necessary improvements for developing and distributing the waters, bonds amounting to $25,000 were issued

in July, 1900. Two thousand dollars of these bonds fall due annually for ten years, beginning with 1906, and $1,000 each year thereafter until they are paid.

POMONA IRRIGATION.

RIGHTS.

The flourishing district about Pomona and Claremont derives its irrigating water from San Antonio Canyon and from numerous wells and pumping plants that have been installed, mainly in the old ciénaga lands in the vicinity of Claremont and about the eastern point of the San Jose Hills. (See Pl. I, *C*, *D*, p. 8.)

The rights to the flowing waters of the canyon date back to Ignacio Palomares, one of the early owners of the San Jose rancho, and to N. Alvarado, a squatter on this tract. Both of these men built ditches from San Antonio Creek and acquired rights to its waters. These rights were subsequently transferred to American purchasers and have been subject to adjustment as between the Pomona and Ontario users, the former holding the old rights to the west-side waters from San Antonio Canyon, and the latter to the east-side waters. As the matter stands at present, the San Antonio Water Company, supplying Ontario and vicinity, and owners of the earliest right on the stream, the Gird or Dexter right, are entitled to the first 20 miner's inches flowing from the canyon. After this amount is taken out, the remainder is divided equally between the east-side and west-side users, until it exceeds 624 inches. All of the flow in excess of this amount belongs to the San Antonio Company, representing the east-side ownership. The Pomona users may therefore receive not to exceed 312 miner's inches of this water, and will receive less than that if the canyon flow falls below 644 inches.

CANYON WATER COMPANY OF POMONA.

About 83 of these 312 inches (or a proportional amount of a smaller flow of canyon water) belong to lands lying in the north Palomares and Martin tracts; the remainder of the flow belongs to the Loup & Meserve tract, and the owners of a larger part of this share organized in 1897 as the Canyon Water Company of Pomona. This company controls 45½ per cent of the west-side San Antonio waters. The remainder of the Loup & Meserve owners maintain their original status of tenants in common.

The Canyon Water Company is capitalized at $312,000, divided into 31,200 shares with a par value of $10 each; 14,169.3 of these shares have been issued. The organization was effected by a number of the holders of canyon water rights, who deeded those rights to the company and received stock in exchange. In 1905 there were 87

stockholders. The majority of the stockholders held 125 shares per 10 acres, some held in excess of this number, and a few had but 100 shares. Each share represents one one-hundredth of a miner's inch when there is enough water flowing in the canyon to give the west-side irrigators their full quota of 312 inches. At other times it represents a smaller amount, whose value is proportional to the water available. The officers of the company state that the cost of the water to users is about 80 cents per acre per year, for maintenance and distribution.

During periods of diminished flow in the canyon the water derived from this source is supplemented by pumped water supplied by several private plants and by the Kingsley Tract Water Company, the Claremont Cooperative Water Company, and the C. W. Brundage Company. This accessory water is arranged for by individual irrigators and not through the company.

Official measurements of the waters of San Antonio Canyon are made three times yearly, on the first Mondays in July, August, and September, as a basis for the division of the waters. The share received by the Pomona irrigators as a result of these measurements from 1900 to 1905 is given in the following table:

Quantity of water, in miner's inches, delivered to Pomona irrigators from San Antonio Canyon, 1900–1905.

Year.	July.	August.	September.
1900	115	(?)	(?)
1901	312	257.07	213.55
1902	170.5	128.06	101.6
1903	312	271.05	214.77
1904	186.935	147.54	132.25
1905	312	312	312

DEL MONTE IRRIGATION COMPANY.

The Del Monte Irrigation Company is one of the four companies distributing water in the Pomona region, organized originally by the Pomona Land and Water Company. The organization of this branch was effected in February, 1887, with a capital stock of $400,000, divided into 40,000 shares with a par value of $10 each; 21,000 shares have been issued at the rate of 10 shares per acre, and the market value was reported in 1906 as $8 per share. There were at that time between 175 and 200 shareholders, all of whom were landowners under the system. Absentee ownership is not permitted.

From the Pomona Land and Water Company the Del Monte Company received the right to the natural flow from Del Monte ciénaga, one-fourth mile southeast of Claremont, and a right to develop water in a tract of 150 to 200 acres there. They also obtained from the same source the right to develop water in a 12-acre tract in

Martin ciénaga, one-fourth mile west of Claremont. In 1899 the company purchased an additional water right covering 68 acres in the Martin ciénaga. The price paid for this right was $25,000.

As early as 1886 artesian wells were bored in the ciénagas, and the number was gradually increased until about 28 in all had been sunk. The artesian flow, however, slowly decreased as a result of the increasing development and the succeeding dry years, and finally ceased in 1897. Thereafter the company depended entirely on pumping. The lift in 1905 was about 80 feet, but decreased markedly as a result of the three succeeding wet years.

In the Del Monte ciénaga the company operates a compressed-air plant, installed in 1899, from which seven wells within a few hundred feet of the plant were pumped in 1905. A Corliss air compressor operated by a 140-horsepower steam engine is used. Three wells in the Martin ciénaga have been pumped from this plant, but they were not in use in 1905. The air compressor, engine, and pipes are reported to have cost $15,000, and the output is given at 155 miner's inches. In addition to this central plant, one well in the Del Monte ciénaga is in use. A 40-horsepower motor and a Pomona deep-well pump are also used in the Martin ciénaga.

The water developed by the pumping plants is divided into four heads, prorated to stock and distributed at intervals of twenty-seven and one-half days by schedule through about 15 miles of 8 to 20 inch cement pipe owned by the company.

Annual assessments of 60 cents per share, or $6 per acre, cover the cost of operating and maintaining the system and interest on indebtedness.

IRRIGATION COMPANY OF POMONA.

The Irrigation Company of Pomona was organized by the Pomona Land and Water Company in July, 1886. It was capitalized at $245,000, divided into 24,500 shares with a par value of $10 each; 2,450 acres were included in the district, and lands in the tract were sold with 10 shares of water stock per acre. All of the stock has been issued. When the majority of the stock had been transferred to the purchasers of land in the district, the management of the company was turned over to them and the organization has since been operated as a mutual water company.

The original sources of water were San Jose Creek and the moist lands in which it rose and a number of artesian wells bored in these lands, which constituted the old artesian belt north of Pomona. About 45 wells have been bored at various times. With continued development and recurring dry seasons these sources of cheaper water failed, the artesian wells ceasing to flow from 1896 to 1899, and now the company depends entirely on pumped water. One large

central pumping plant (No. 182, Pomona quadrangle) has been installed, and from this station, equipped with a 150-horsepower Corliss-Cross compound air compressor, 16 wells, the farthest half a mile away, are pumped. Smaller auxiliary plants have been used in the past, but were abandoned for the more economical concentrated system. It is estimated that the company has, in addition to the pumping plant, about 25 miles of iron and cement distributing pipe, varying from 6 to 20 inches in diameter. It owns one reservoir on Holt avenue, east of Pomona, whose capacity is 1,900,000 galions. It also has the right to develop water on 200 acres of ground in the vicinity of the plant.

The company pumps for about seven months in the year, and produces from 200 to 250 inches continuous flow during this period. The water is divided into four heads, and each block of 100 shares of stock is given a twelve-hour run of one head monthly.

The expenses of maintenance, operation, and distribution are met by assessments on the stock, which amount to about 40 cents per share, or $4 per acre annually.

Of the 2,000 acres irrigated by this company, one-third is planted to citrus fruits and the remainder to diversified crops.

PALOMARES IRRIGATION COMPANY.

The Palomares Irrigation Company is one of the four companies organized by the Pomona Land and Water Company and succeeding to its rights. The organization was effected on February 23, 1887, with a capital stock of $60,000, divided into 6,000 shares at $10 per share. The water rights which the company owned were made appurtenant to 600 acres of land, and 10 shares of stock were sold with each acre.

The original source of the water used was a group of five artesian wells near the northern edge of the Pomona artesian area. These wells ceased to flow, with others in the same belt, in the late nineties. A pumping plant was then installed, and by its use from 40 to 80 inches of water are now procured from two wells (No. 291, Cucamonga quadrangle) and carried through a 22-inch main in a southeasterly direction to the Palomares tract, which lies between the territory covered by the Irrigation Company of Pomona and that served by the Del Monte Irrigation Company.

Pumping is usually begun in April and is continued thirty days per month and twenty-four hours per day until November. The water is distributed in full heads of 40 to 80 inches, each 100 shares receiving a twelve-hour run monthly.

The expenses involved in the maintenance of the plant and the distribution of the water are met by an annual assessment on the shareholders. For a number of years this assessment varied between a minimum of $3 and a maximum of $6 per acre annually.

CONSOLIDATED WATER COMPANY OF POMONA.

The Consolidated Water Company of Pomona was organized by Messrs. Becket, Brady, and Lathrop, and incorporated May 23, 1889, with a capital stock of $500,000, divided into 5,000 shares of $100 par value each.

The company serves the city of Pomona with water for domestic purposes. The supply is obtained from five pumping plants located in the old artesian basin about three-fourths of a mile south of North Pomona and from wells and tunnels in San Antonio Wash, one-fourth of a mile east of Indian Hill. Four of the five plants were installed in 1897 and 1898, and the fifth in the spring of 1904. Three of them are equipped with Addison-Lindsey deep-well lift pumps and two with centrifugal pumps. Electric power is used, and the combined capacity of the five plants is given at 200 inches. The cost is stated to be about $15,000.

In the years 1892–1896 land east of Indian Hill was purchased from Peter Fleming and James Becket, and a tunnel was driven into the wash in order to develop a gravity flow. This tunnel, starting at the surface near Claremont, is about 1 mile in length and reaches a depth of 120 feet at the upper end. Two wells have been sunk along it and now flow into it. A pipe line has also been laid along the lower part of the tunnel, and this section filled. The combined cost of the land, tunnel, and wells is given as $150,000.

The flow from this system varies with the season and the rainfall. During the winter months it reaches 160 inches, and is then ample for the city's needs. During the summer season, when the demands are heavy, the flow decreases, and an auxiliary supply is furnished by the pumping plants. Early in June, 1904, the flow from the wells and tunnel was reported at 70 inches, and during July of the same year, 54 inches. The city requires about 130 inches during the heated term, a large amount being applied to lawns, shrubbery, gardens, etc.

In 1905 the company reported 1,500 taps in active use. A part of the service is equipped with meters, of which there were then about 300, more than half of them owned by the consumers. Citizens may install meters at any time at a cost of $12, and pay thereafter for the actual amount of water used. Where meters are not used, the charges are regulated in great detail by city ordinance. An idea of the rates may be obtained from the following items: A charge of $1 per month is made for houses of five and six rooms, and 10 cents per month for each additional room. For irrigating lawns, 25 cents per month is charged throughout the year for 50 square yards or less, and one-fourth of a cent for each additional yard. Where meters are installed the following rates were established for the year beginning July 1, 1904: Minimum rate, 600 cubic feet or less, per month, $1; each additional 100 cubic feet to 2,500 cubic feet, 10 cents; each 100 cubic

feet over 2,500 cubic feet, 8 cents. In its collecting and distributing system the company owns 6.6 miles of cement pipe, 8 to 20 inches in diameter; 9.4 miles of iron pressure pipe, 6 to 16 inches in diameter; 43.5 miles of iron pressure pipe, 2 to 5 inches in diameter; and 1 reservoir, capacity 1,000,000 gallons.

The cost of this system is about $90,000, while the total investment in lands, water rights, tunnels, wells, pumping plants, and distributing systems is given as $362,000.

KINGSLEY TRACT WATER COMPANY (LIMITED).

The irrigating enterprise known as the Kingsley Tract Water Company (Limited) was incorporated September 10, 1900, and capitalized at $53,625, divided into 5,362½ shares of a par value of $10 per share. About 2,900 shares have been issued to the 55 stockholders, and the water is distributed to these and to five tenants in common on the tract who have not come into the corporation.

The Kingsley tract is located northeast of Pomona, and is a part of the original Loup & Meserve tract, to which a portion of the San Antonio Canyon water is appurtenant. The Kingsley Tract Water Company is a mutual water-supply company, organized to distribute the stockholders' share of the canyon water and to develop and control a supply of domestic water. It has no control over the canyon water, but, with the the consent of the holders of canyon rights, distributes their water and collects assessments for maintaining the canyon system. When the flow from San Antonio Canyon apportioned to Pomona irrigators equals 312 inches, the Kingsley tract receives 52.65 inches, and the same proportion of a lesser flow. The company pumps domestic water and an auxiliary supply for irrigation from well No. 280 (Cucamonga quadrangle). Pumped water is used for irrigation only when necessary to keep the canyon head up to the regular amount. The well was sunk in 1884 by S. B. Kingsley, under contract with R. Cathcart, the owner of the property on which it is located. It was once artesian but it ceased flowing about 1892. By the terms of the contract Mr. Cathcart retained a two-fifths interest in the well and guaranteed a protection strip of 600 feet surrounding it.

The pumping plant, consisting of a 30-horsepower gas engine and centrifugal pump, was installed in 1898 or 1899. It has a capacity of 30 inches. The water is piped a distance of half a mile southeastward to a reservoir in the upper part of the tract, and thence is distributed to two smaller reservoirs. The large reservoir is 300 feet in diameter and 12 feet deep. Because of the large storage capacity of the reservoirs, night and Sunday irrigation is unnecessary. The distributing system consists of 6½ miles of irrigating pipe from 6 to 10 inches in diameter, and of about the same amount of iron pipe for domestic supply, from 1 to 4 inches in diameter.

Canyon water costs the irrigators about $2 per miner's inch per year, and pumped water is supplied at cost to the stockholders. About 350 acres are partially supplied with irrigating water, and domestic water is furnished to 55 families. The water is distributed in 25-inch heads, each acre being given a 102-minute run every two weeks. This is about equivalent to 1 miner's inch constant flow to 8 acres. For any excess over the regular head irrigators pay 2 cents per hour-inch.

Including the Loup & Meserve tract assessment of $104, the cost of operating and maintaining the system from January 1, 1904, to January 1, 1905, was $1,768. During the same period $2,546 was spent in development and new machinery. These charges are met by assessments on the stock.

MOUNTAIN VIEW WATER COMPANY.

The Mountain View Water Company is the successor of the old Fleming & Rohrer works, which consisted of several miles of pipe line and several hundred feet of tunnel driven into an outcrop of the old red alluvium that is exposed in San Antonio Wash about 1½ miles east of Indian Hill. With these earlier works the company acquired 480 acres of land, paying for the land and the developments $13,875. After acquiring the property the company sunk several wells and extended the tunnels to tap them. In July, 1896, a corporation was formed, the capital stock being fixed at $45,000, divided into 13,875 shares. This stock is not appurtenant to the land, but is held only by landowners.

In 1895 the gravity flow from the tunnel and wells reached 138 inches, but during the succeeding years the output diminished, and in 1899 two pumping plants were installed. These plants consist of 18- and 12-horsepower gas engines and centrifugal pumps. Their combined capacity is 45 miner's inches. During the winter season one well (No. 111, Cucamonga quadrangle) still flows a small amount into the tunnel. In the distributing system there are about 5 miles of 6- to 16-inch pipe.

The water developed is piped to the east a distance of 1½ miles and used on the Mountain View tract, about 1½ miles northwest of Upland, except for three days of each month, when it is conducted to the village of Claremont and used there for domestic supply. There are about 400 acres under irrigation in this system, and the water is distributed monthly in 30-inch heads on the basis of 1 inch to 10 acres. The cost of the water to the users is approximately $50 per inch, or $5 per acre annually.

CANYON RIDGE WATER COMPANY.

The Canyon Ridge Water Company is a small company which irrigates about 160 acres of land northwest of Upland, near the Mountain View Water Company's tract. It was incorporated March 12, 1900, and capitalized at $20,000, divided into 400 shares with a par value of $50 each. The stock is distributed among irrigators only. The company owns 10 acres of land in the upper part of the Ontario colony tract, on which a well has been sunk (No. 86, Cucamonga quadrangle) and a pumping plant installed. The plant consists of a 20-horsepower gas engine and a deep-well pump with a capacity of 25 miner's inches. About 2½ miles of 6-inch pipe are laid down the slope to the stockholders' lands, where the water is used. Distribution is effected in full heads in rotation at intervals of thirty days. The cost of the water to the users is given at about $60 per inch annually.

UPLAND WATER COMPANY.

The Upland Water Company is a corporation organized principally by stockholders of the Mountain View Water Company for the purpose of developing an auxiliary supply. The organization was effected in 1900, on the basis of a $30,000 capitalization divided into 300 shares. During the same year the company bought 30 acres of land, east of Upland and north of the Red Hills, sunk a well (No. 58, Cucamonga quadrangle), and installed a pumping plant. The original plant, consisting of a steam engine and Worthington pump, was replaced in 1905 by an electric motor and Pomona deep-well pump. The total investment in well and plant up to 1905 was about $1,200.

The capacity of the plant is reported as 40 inches. The water produced flows through about 26,000 feet of 10- and 8-inch cement pipe to the Mountain View tract, west of Upland, where it is distributed monthly in full heads to the stockholders, who are all irrigators. The cost of the water per annum is given as $10 per acre.

ORANGE GROVE TRACT WATER COMPANY.

The Orange Grove Tract Water Company was organized in 1889 by John E. Packard, who owned artesian water-bearing lands north of Pomona and about three-fourths of a mile from the easternmost point of the San Jose Hills. Mr. Packard sunk wells on this property, laid pipe lines and constructed reservoirs, and sold the rights to 14½ inches of water to the owners of the Vineyard tract of 80 acres, located in the present city of Pomona. A large part of the Vineyard tract has since been cut up into city lots. The water right of the

23 acres north of Pomona, on which the pumping plant is situated, was transferred by Mr. Packard to the Orange Grove Water Company, subject to the prior right of 14½ inches, made appurtenant to the Vineyard tract, as mentioned above.

Lands of the present Orange Grove tract, which lies south of the San Jose Hills and west of Pomona on Holt avenue, were sold with 10 shares of water stock per acre. Four thousand seven hundred and twenty shares were issued, covering 472 acres. There are 26 stockholders in the company, and all water developed except that belonging to the Vineyard tract is used by them. None is sold outside.

In the late nineties the artesian flow of the wells ceased, and about 1899 the company put in a pumping plant. This plant was installed for the purpose of supplying the Orange Grove company with domestic water and the Vineyard tract with the 14½ inches to which it was entitled. The plant consists of a 25-horsepower gas engine and a centrifugal pump. It is in operation throughout the year.

For irrigating purposes the company utilizes the water developed from the Alkire tunnel, which it has leased for a term of years. This tunnel, constructed by Josiah Alkire, is located close to the eastern point of the San Jose Hills and intercepts a part of the underflow around that point. The flow from this tunnel during August, 1905, was stated by Mr. French, the secretary of the company, to be 28 inches. The water developed is delivered to the Orange Grove tract and distributed in open ditches in 20-inch heads, each acre being given a run of three and three-fourths hours per month.

The combined cost of irrigating and domestic water during the four years from 1902–1905 is reported to have been about $5 per acre. This was covered by assessments on the stock.

CLAREMONT COOPERATIVE POWER COMPANY.

The Claremont Cooperative Water Company was organized in 1902, and 90 acres of land close to the foothills 2 miles northwest of Claremont were purchased. A well and pumping plant which had already been installed on the property were included in the purchase.

The lands on which the water is used lie just north of Claremont, and the water is delivered to them through about 2¾ miles of 12- and 8-inch cement pipe. The plant has a capacity of 30 miner's inches, but only about 60 acres are irrigated. No water is sold, the stockholders of the company using all that is pumped. The cost to them is reported to be about 1¼ cents per hour-inch.

CITIZENS' LIGHT AND POWER COMPANY.

The Citizens' Light and Power Company was organized principally for the purpose of supplying the village of Claremont with domestic water. It was incorporated December 6, 1902, on a basis of 1,045 shares of stock of a par value of $10 per share, making a total capital of $10,450.

In April, 1903, 40 acres of land were purchased, high up on the slope above Claremont, about 1 mile from the foothills. Development was begun on this property the same season. A well was sunk and equipped with a 25-horsepower gas engine and Pomona plunger pump, an 8- or 10-inch main was laid to the village 2 miles below, and a reservoir with a capacity of 1,250,000 gallons was constructed. The plant will produce about 25 inches of water.

CHINO LAND AND WATER COMPANY.

The Chino Land and Water Company was organized in 1900, with a capital stock of $1,500,000, divided into 15,000 shares, the par value of each being $100. It succeeded to the holdings of Richard Gird, of Chino, these holdings including the greater part of the Chino ranch of 37,500 acres, with certain water rights and obligations. The company owns 14 or 15 flowing wells in the Chino artesian belt and two pumping plants.

The greater part of the water supply is furnished by a group of ten artesian wells, situated about 1¼ miles southwest of Chino. The water from this group is conducted for several miles in a southeasterly direction through an earthen ditch, to 600 or 700 acres of alfalfa land to which it is applied. The artesian flow is supplemented during the heated term by the water yielded by a pumping plant installed in 1903, about half a mile from the artesian group.

A second pumping plant, which supplies the village of Chino with domestic water, is situated about 1½ miles north of Pomona. This plant was installed in 1901, and a portion of its product is sometimes sold to outsiders. The well is one of the original Gird group, bored in the early eighties, and is reported to have yielded 80 inches of artesian water when first put down. There were 23 of these wells, drilled in the old Palomares ciénaga, and their reported total yield in the latter part of the decade between 1880 and 1890, is 300 or 350 inches. A pipe line with a capacity of 300 inches was laid by Mr. Gird from the wells to the vicinity of Chino, and his total investment in wells, pipe lines, and water rights is given as $200,000. The wells failed rapidly, however, and all ceased flowing in the years 1888 to 1891, and since Mr. Gird had agreed not to pump them, they have all been abandoned, except Nos. 280 and 287, Cucamonga quadrangle,

over which pumping plants have been installed, and five or six others which are used by ranchers for domestic supply.

Some supplementary irrigation is accomplished on the Chino rancho by the use of waste waters from the beet-sugar factory at Chino. A group of 15 wells is pumped by compressed air for the use of the factory when it is in operation, and the waste is conducted south of Chino to lands on the north and south banks of Chino Creek.

SAN JOSE VALLEY SYSTEMS.

CURRIER TRACT WATER COMPANY.

The Currier Tract Water Company was incorporated in September, 1900, with a capital stock of $10,000, divided into 300 shares, whose par value is $33.33 each. There are at present 35 stockholders in the company. The company owns a well and pumping plant (No. 1, Pomona quadrangle), located a short distance west of Pomona. The plant consists of a 30-horsepower electric motor and centrifugal pump, which with the well cost $3,300. In addition to this plant, 1¼ miles of 10-inch cement pipe have been laid at an expense of $2,300, bringing the total investment up to $5,600. From this plant about 100 acres, principally in citrus fruits, are irrigated. It is reported by officers of the company that in July, 1905, an official measurement was made which indicated an output of 56 miner's inches from the plant. Costs are given as 85 cents per hour for pumping, while the total cost for operation and maintenance is from $550 to $560 annually.

A. T. CURRIER DEVELOPMENT.

The plant of A. T. Currier is a private enterprise, but its magnitude justifies a brief description. It consists of two wells located on the south bank of San Jose Creek about 1½ miles below Spadra, 560 feet of wooden flume, and 3¼ miles of 18- and 20-inch vitrified pipe, through which the water is carried along the foot of the hills south of San Jose Creek valley, the line terminating south of Lemon. The wells were sunk in 1902 to bed rock, which was reached at 80 and 115 feet, and the pipe line was laid during the same year, at a total expense of $15,400.

NORTH DITCH.

The old irrigation work formerly known as the Rowland & Foster ditch diverts water from the bed of San Jose Creek about 1½ miles northeast of Lemon. It follows the creek for one-fourth mile until it attains the elevation of the bottom lands, thence it passes due west across the valley for about 1 mile. The original ditch was built fifty or sixty years ago by the Spanish, but the present work, a dirt ditch throughout, was dug in 1885.

The water supply from the creek varies with the season, but is usually less than 40 miner's inches. The supply being lowest during the summer season, when irrigating water is most needed, it has been found necessary to supplement it by installing pumping plants, four of which are in operation. The water is used by the ranchers in the Lemon district on the north side of the creek, who irrigate from 100 to 125 acres. The entire head is distributed on the basis of one hour per acre each twenty-one days.

SOUTH DITCH.

About one-half mile below the diversion dam on San Jose Creek at the head of the combined north and south ditches the water is divided and half the flow is carried across the creek by flume and through the south ditch for about 2 miles in a southwesterly direction to the ranches which are served by it on the south side of the valley. Eleven individual ranchers are entitled to the water from this ditch, but as the flow is much too small for the acreage under cultivation, five or six pumping plants have been established to furnish an additional supply. The north and south ditches share the water of San Jose Creek at their common diversion point equally, each receiving, it is said, from 15 to 40 miner's inches. On the south ditch the full head is distributed on the basis of one hour per acre each twenty-five days.

LORDSBURG WATER COMPANY.

The Lordsburg Water Company was incorporated December 5, 1900, with a capital stock of $36,000, divided into 3,600 shares, with a par value of $10 each. Before the incorporation of the company its organizers had sunk wells, installed pumping plants, and laid a pipe line, at an expense of nearly $12,500. This property was exchanged for the stock, which is distributed among 35 shareholders. Three thousand five hundred shares were issued to the original owners, while 100 shares were retained as treasury stock. Later the company purchased some stock, so that in 1905 there were but 3,146 shares out.

The company owns three wells, two of which (Nos. 50 and 63, Pomona quadrangle) are in use. One of these wells is pumped by a 20-horsepower electric motor and the other by a 24-horsepower gas engine. The officers of the company report that from 50 to 60 miner's inches are developed by the two plants.

The distributing system includes about 5 miles of pipe line, nearly 3½ miles of which are in the main conduit, which extends northwestward from the pumping plants to San Dimas Wash and connects with the San Dimas, Covina, and Azusa irrigating systems. This conduit is 16, 12, and 10 inches in diameter, according to grade, and has a capacity of 120 to 140 miner's inches.

The cost of the water is given by the company's officers as about 1½ cents per hour-inch. Some stockholders have more water than they need, and sales are sometimes made to outsiders at a rate of 2½ cents per hour-inch.

There are 300 acres irrigated by the company, 40 acres south of the plant at Lordsburg and the balance below the pipe line between Lordsburg and San Dimas. Citrus fruits, alfalfa, and potatoes are grown.

LAVERNE LAND AND WATER COMPANY.

The Laverne Land and Water Company is a cooperative concern, organized and incorporated October 30, 1899. The capitalization is $25,000, divided into 500 shares whose par value is $50 each. The paid-up capital represents about one-half of the capital stock, 241½ shares having been issued.

At the time of the organization of the company 15 acres of land were purchased, and in 1900 two wells (No. 249, Pomona quadrangle) were sunk on this property, which lies 1½ miles northeast of Lordsburg. A 38-horsepower gas engine and two deep-well pumps, with a combined capacity of 55 inches, were installed, and 3 miles of cement, steel, and vitrified pipe were laid west and northwest from the plant for the delivery of water to the lands under irrigation. Both pumps are in operation only when the demand for water is large. The company reports that in 1903 one pump was used 1,087 hours and two pumps were used 1,402 hours, and that in 1904 one pump was used 650 hours and two pumps were used 3,170 hours.

A charge of 75 cents per hour is made for the output of both pumps, a rate of $1\frac{4}{11}$ cents per hour-inch when the full head of 55 inches is delivered; and 40 cents per hour is charged for the output of one pump.

The water is used to irrigate 241 acres of citrus fruits. Each acre is given a two and one-half hours' run of a full head every thirty days, which is equivalent to a duty of 1 inch continuous flow to 5.3 acres when the full head of 55 inches is delivered. Water in excess of the regular supply is sometimes furnished to stockholders and to outsiders. In these cases a charge of 3 cents per hour-inch is made.

LEVERNE IRRIGATING COMPANY.

The Laverne Irrigating Company was incorporated March 17, 1902, with a capital stock of $25,000, divided into 500 shares. One acre of land with a water right to 5 acres and one-third interest in a well and pumping plant were acquired at Laverne, 1 mile east of San Dimas, from L. T. Gillett. The well had been sunk, the plant installed, and the pipe line laid in 1900. The pumping machinery consists of a 35-horsepower gas engine and centrifugal pump No. 4 and the distributing system of 2 miles of 10-inch cement pipe. One hundred

acres of citrus fruits are irrigated, the water costing, it is reported, 1 cent per hour-inch. Water is distributed in full heads at thirty-day intervals.

SAN DIMAS IRRIGATION COMPANY.

In 1885 Messrs. Lyman, Allen, and Bixby, owners of riparian water rights in San Dimas Canyon, which they had purchased from Messrs. Brooks and Rogers, who made the original filings, laid an 8-inch pipe from the bed of San Dimas Creek out to the mesa lands east of the wash. During the same year they organized the San Dimas Land and Water Company, capitalizing it at $60,000, with 1,200 shares of of stock, 1,025 of which have been issued. The San Jose Ranch Company was organized in April, 1887, with a capital stock of $300,000, and controlled several thousand acres of land lying south of San Dimas Wash and extending westward to the Covina district. Its water rights covered the "Mud Springs" ciénaga, 1 mile southeast of San Dimas; the developments in Sycamore Flat Canyon, which then yielded 10 to 15 inches, but have since been abandoned; and certain claims on the flow of San Dimas Canyon based on the company's holdings of lands in the upper part of the canyon. In addition, it took possession of the water rights and development work of the San Dimas Land and Water Company, agreeing in return to furnish the latter company with 35 miner's inches constant flow.

Extended and expensive developments were at once undertaken. A 12- and 14-inch cement conduit was laid from the masonry forebay at the opening of San Dimas Canyon to the plain on the south, which formed a part of the large tract controlled by the Ranch Company. Sixteen 7-inch wells were sunk in the Mud Springs ciénaga, and a tunnel was driven to cut the wells at points varying from 20 to 30 feet below the surface. During the year of organization (1887) and the five years following, 3,300 feet of 3- by 6-foot tunnel were constructed in the ciénaga and a gravity flow was developed which is reported to have at one time reached a maximum of 77 miner's inches. From the canyon line and the Mud Springs ciénaga, 12 to 14 miles of 8- by 10-inch cement distributing pipe were laid to the ranch lands lying west of these sources. While these expenditures were being made, lands with water rights were sold, and by 1891 these rights, aggregating 160 inches, had been disposed of on the basis of $1,000 per inch. The company, unwisely managed from the start, had expended in various ways the money derived from the sale of the lands, but had made no adequate provision for obtaining the water which it had agreed to supply.

During the years 1891 to 1894 the flow from the only sources, San Dimas Canyon and Mud Springs ciénaga, gradually declined, and the company, unable to meet the demands of those who had bought

water from it, offered to turn over to them its remaining assets, consisting of pipe and tunnel systems, various water rights, and $3,000 in cash. This offer was declined, and suit was instituted against the company to compel the delivery of the full quota of water according to contract; but a minority of the ranchers, believing that the company was exempt from penalty through the operation of the statute of limitations, withdrew from the suit, and after negotiations with the San Jose Ranch Company organized the San Dimas Irrigation Company on October 15, 1894. This company was capitalized at $160,000, divided into 1,600 shares, and to it the system of pipe lines and tunnels belonging to the Ranch Company was deeded. It was provided also that other purchasers of water rights from the San Jose Ranch Company should be allowed to join the new company within a year, the applicant to receive 10 shares of stock in the new organization for each inch of water purchased from the old.

Immediately after the formation of the San Dimas Irrigation Company, suit was brought to determine the ownership of the water from the Mud Springs ciénaga. In 1896 a decision was rendered, awarding this water, which had now fallen to 33 inches, according to precedence in use, thus leaving all except the first users without water. These first users shortly afterward organized the Ciénaga Land and Water Company.

The flow from the Mud Springs continued to decline, but the Ciénaga Company was unable to pump because the wells and tunnels belonged to the San Dimas Irrigation Company, and the latter company was unable to pump because the water belonged to the Ciénaga Company. This deadlock was broken by an agreement reached in 1898, whereby the San Dimas Irrigation Company agreed to install a pumping plant and deliver to the Ciénaga Land and Water Company, free of charge, 33 miner's inches, but reserved the privilege of turning the plant over to the Ciénaga Company at any time, allowing the latter company to pump the 33 inches at its own expense. In case this was done the San Dimas Irrigation Company was to be permitted to enter on the ciénaga lands and install an independent plant there.

In accordance with the terms of this agreement, the San Dimas Company installed a plant in 1898, and for three years delivered 33 miner's inches to the Ciénaga Company free of charge. At the end of this period, becoming dissatisfied, the San Dimas Company took advantage of the option in the agreement of 1898, and for one year the plant was operated at the expense of the Ciénaga Company, and but 33 inches developed. Finally, the latter company claiming that the cost of pumping under this arrangement was excessive, a contract was entered into, by the terms of which the San Dimas Company agreed to furnish the Ciénaga Company with 33 inches at

a charge of three-fourths of a cent per hour-inch. This contract expired in December, 1907.

In 1895 it was discovered that a large body of water underlay San Dimas Wash, and from that time on many wells were sunk there and plants were established to supplement the supply in the surrounding districts. The San Dimas Irrigation Company, among others, entered this district in 1900, purchased land, put in a well, and erected a pumping plant. In 1904, because of the increased demand and the lowering of the water plane, a second, deeper well, 14 inches in diameter, was bored in the wash, and a 75-horsepower electric motor installed over it. The two wells there yielded 60 miner's inches after these improvements were completed.

In 1902 a well was sunk and equipped with pumping machinery on Bonita avenue, about one-fourth mile north of the Mud Springs ciénaga, and a considerable addition to the supply was thus obtained. At times, also, water has been purchased from outside systems when available at a reasonable price, and by these various means the supply has been kept equal to the demand. The only gravity water owned by the company is the tenth part of the flow of San Dimas Canyon, when the total is 37½ inches or less, and one-half of all in excess of this amount. Title to this share is a result of the compromise of January, 1905, which ended the long suit between the San Dimas Land and Water Company and other claimants to San Dimas Canyon water.

Stock of the San Dimas Irrigation Company is held exclusively by landowners, and the basis of distribution is 1 inch to 10 acres. Water rates are established yearly and are controlled by the cost of pumping. All improvement and maintenance charges are met by separate assessments.

In addition to the water owned by the company, about 150 inches of alien water produced by independent pumping plants is distributed through the San Dimas system, one-fourth cent per hour-inch being charged for this service.

Of the 3,000 acres irrigated in the San Dimas district, about 1,050 are supplied by the San Dimas Irrigation Company. Its assets are distributed about as follows: Pipe lines, 20 miles of 8- to 18-inch pipe, $30,000; wells and three pumping plants, $26,000; three pumping-plant sites, $2,300; land in San Dimas Canyon, $1,000; total, $59,300.

ARTESIAN BELT WATER COMPANY.

The Artesian Belt Water Company was incorporated August 14, 1897, and capitalized at $30,000, divided into 300 shares, which are distributed among 64 stockholders. This was one of the first companies organized in the San Dimas district for the purpose of developing and distributing pumped water, and it now owns and pumps the first well sunk there (No. 234, Pomona quadrangle). This well was

bored in 1895 and the first plant was installed in 1896 by J. O. Enell. The original plant was a 30-horsepower boiler and duplex steam pump. Now a 54-horsepower engine is used. When the well was first bored water was encountered at 44 feet from the surface, but the water plane has since declined so that the lift is now much more than this.

In addition to the well and plant, the company owns 10 acres of land in San Dimas Wash and about 2½ miles of 12-inch cement pipe, the total estimated investment being $20,000. The distribution of the waters and the administration of the company are managed much as in the larger San Dimas Irrigation Company, several landowners being stockholders in both organizations.

NEW DEAL LAND AND WATER COMPANY.

The New Deal Land and Water Company was organized September 25, 1890, with a capital stock of $100,000, divided into 2,000 shares. It owns and operates a well and pumping plant (No. 236, Pomona quadrangle), 1 mile southeast of San Dimas, near the old Mud Springs ciénaga. The property on which the plant is located was purchased on the supposition that in the original deed from the San Jose Ranch Company no reservation had been made of the rights to the underground water in this vicinity, but after the transfer of the Ranch Company's rights to the San Dimas Irrigation Company, the latter organization claimed all underground waters in the vicinity of the springs, and the matter was carried to the courts. An agreement was finally reached, however, by the terms of which the New Deal Land and Water Company was given the right to sink and maintain its present well and was guaranteed a protection strip within a radius of 75 feet of the plant. The plant consists of a 12-horsepower gas engine and a No. 2 Fulton pump, and produces from 10 to 20 inches of water, with which about 100 acres of citrus fruits are irrigated.

FROSTLESS BELT WATER COMPANY.

The Frostless Belt Water Company was incorporated in April, 1901, with a capital stock of $10,000, divided into 1,000 shares, all of which have been issued. There are 13 stockholders, 10 of whom also own stock in the San Dimas Irrigation Company.

Soon after its organization the company purchased 20 acres of land at Laverne at a cost of $1,500, and not long thereafter a well was bored (No. 224, Pomona quadrangle) and equipped with a 30-horsepower gas engine and centrifugal pump. The plant is reported to yield 30 miner's inches. About 12,000 feet of 10-inch cement pipe have been laid for delivering the water to the lands of the stockholders southwest of San Dimas. The water is delivered in full heads of 25 to 30 inches at thirty-day intervals, at the rate of 1½ inches to 10 acres. Citrus

fruits are raised. The company reports its investments as follows: Well and plant, $2,800; pipe line, $3,300; real estate, $1,500; total, $7,600.

SAN GABRIEL SYSTEMS.

HISTORY OF RIGHTS.

Wm. Ham. Hall states that the church fathers are reported to have taken water from San Gabriel River as early as 1821 for irrigation in the neighborhood of the San Gabriel mission. None of the present rights, however, date back to this earliest diversion, if it was actually made. The oldest of the present ditches is the Azusa, built in 1843 by Luis Arenas, owner at that time of the Azusa rancho. Eleven years later Andrés Duarte, who owned the Duarte rancho, built a second west-side ditch, to which some of the west-side irrigators claim their rights are traceable.

In 1852 or 1853 Mr. Dalton, who had meanwhile acquired the Azusa rancho, enlarged the east-side ditch, and disputes quickly arose, both as to the boundaries of the rancho and as to the ownership of the water carried in the enlarged ditch, settlers on the lower part of the ranch claiming a proportion of the waters carried in it. The period which intervened up to 1889 was one of much confusion. Disputes, litigation, and compromises were of repeated occurrence, the settlements which resulted from the latter often being of short duration. At the same time other settlers were taking up lands, and the interests involved became constantly greater and more complex. Slauson & Martz, from whose interests the Azusa Agricultural Water Company was later developed, secured possession of the Azusa ranch between 1880 and 1883, and in 1882 the Azusa Water Development and Irrigating Company, later the Covina Irrigating Company, began a tunnel for developing the underflow of the San Gabriel. This tunnel was completed in 1889, although the canal by which its waters were carried to a district east and south of that served by the older Azusa canal had been finished about 1885. The builders of this tunnel claimed to have developed by its construction 137 miner's inches of water, but the claim was disputed by the other companies interested in the San Gabriel flow. January 26, 1889, all of the claimants to San Gabriel River waters entered into an agreement, by the terms of which the water was divided among them, and perfected a scheme for controlling its distribution. For purposes of division the water was considered as consisting of 720 parts. When the total quantity is equal to or less than 1,700 miner's inches, each of the claimants gets a certain number of these parts, while the excess above 1,700 inches is divided somewhat differently. The number of 720ths that each claimant to the first

1,700 inches and to the excess receives, as agreed on in this compromise, is given in the following table:

Division of San Gabriel River waters.

[In seven hundred and twentieths.]

	First 1,700 inches.	Excess.
Azusa Water Development and Irrigating Co	72	241
Duarte Mutual Irrigation and Canal Co. and Beardslee Water Ditch Co	216	160
Azusa Land and Water Co	45	33
Azusa Agricultural Water Co	54	40
Kate S. Vosburg and Louise McNiel	27	20
"Old users," represented in part by the Azusa Irrigating Co. and Azusa Water Development and Irrigating Co	306	226

At the time of the compromise a committee of nine members, appointed by the several companies and associated irrigators, was given control of the water from its source to the point of division between the east-side and west-side users. Subcommittees, representing the respective interests, take charge of the water below this point.

This compromise served as a basis for the division of the water until the completion of the San Gabriel Power Company's conduit in 1898. After this conduit was built the power company claimed as salvage and was allowed one-tenth of all the canyon flow except 200 inches, which it was agreed to consider as developed by the Covina tunnel. This tenth was deducted proportionately from the share of each of the users under the compromise agreement of 1889, and on August 1, 1898, the salvage water was purchased from the power company by the Covina Irrigating Company for $66,500, and is now owned and used by the latter organization. The old apportionment, except as it is modified by this salvage agreement, is still in force. An account of the later developments is given in connection with the sketch of each of the companies that follows. The quantity of water available in the San Gabriel for all users and the fluctuations in the flow of the stream are shown in the accompanying tables, taken from the records of the United States Geological Survey. The minimum discharge of which there is record is 3 second-feet, reached in July and September, 1899, and in September, 1900; the maximum is the flood of March, 1905, with a discharge of 11,130 second-feet.

Estimated monthly discharge of San Gabriel River and canals at Azusa, Los Angeles County, 1896–1906.

[Drainage area, 222 square miles.]

	Discharge.			Total discharge.	Run-off.	
	Maximum.	Minimum.	Mean.		Per square mile.	Depth.
1896.	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*	*Acre-feet.*	*Sec.-feet.*	*Inches.*
January	51	26	37	2,275	0.17	0.20
February	61	36	41	2,358	.18	.19
March	169	37	111	6,825	.50	.58
April	91	40	54	3,213	.24	.27
May	40	29	36	2,214	.16	.18
June	27	13	19	1,131	.09	.10
July	15	9	12	738	.05	.06
August	36	9	14	861	.06	.07
September	19	11	13	774	.06	.07
October	188	10	24	1,476	.11	.13
November	40	15	19	1,131	.09	.10
December	37	17	22	1,353	.10	.12
The year	188	9	34	24,349	.15	2.07
1897.						
January	147	25	57.9	3,617	.260	.292
February	1,713	64	344.8	19,146	1.553	1.579
March	1,765	294	465.6	28,623	2.097	2.418
April	370	201	294.4	17,519	1.325	1.478
May	196	94	145.0	8,851	.653	.748
June	91	54	67.8	4,033	.306	.341
July	52	27	38.1	2,343	.171	.197
August	34	22	26.4	1,613	.118	.136
September	23	18	20.7	1,226	.088	.098
October	1,640	22	90.5	5,564	.403	.465
November	34	31	33.3	1,860	.141	.149
December	34	28	30.5	1,875	.137	.158
The year	1,765	18	134.6	96,270	.604	8.059
1898.						
January	63	28	40	2,453	.18	.20
February	70	32	40	2,241	.18	.19
March	48	28	35	2,131	.16	.18
April	37	25.3	33	1,950	.15	.17
May	83	25.0	36	2,223	.16	.19
June	30	14.5	19	1,159	.09	.10
July	14	9.0	11	672	.05	.06
August	9	5.0	7	456	.03	.04
September	10	6.1	8	467	.04	.04
October	10	7.5	9	533	.04	.05
November	11	8.0	10	580	.04	.05
December	18	11.7	14	832	.06	.07
The year	83	5.0	22	15,697	.10	1.34
1899.						
January	33	15	23	1,414	.104	.120
February	28	20	22	1,244	.102	.106
March	40	18	26	1,623	.119	.137
April	28	16	21	1,262	.096	.107
May	17	12	14	842	.062	.071
June	22	5	10	565	.043	.048
July	4	3	4	221	.016	.018
August	6	4	5	295	.022	.025
September	6	3	4	220	.019	.021
October	26	4	11	709	.050	.058
November	24	10	14	847	.064	.071
December	39	16	20	1,247	.091	.105
The year	40	3	14.5	10,489	.065	.887
1900.						
January	89	22	32	1,968	.14	.16
February	23	18	20	1,111	.09	.09
March	30	16	20	1,230	.09	.10
April	26	13	17	1,012	.08	.09
May	86	16	37	2,275	.17	.20
June	22	8	15	893	.07	.08
July	10	4	6	369	.03	.03
August	5	4	4	246	02	.02
September	6	3	4	238	.02	.02
October	6	4	5	307	.02	.02
November	5,200	5	186	11,068	84	.93
December 1–16	53	31	40	1,269	.18	.11
The year	5,200	3	32	21,986	.15	1.85

Estimated monthly discharge of San Gabriel River and canals at Azusa, Los Angeles County, 1896–1906—Continued.

[Drainage area, 222 square miles.]

	Discharge.			Total discharge.	Run-off.	
	Maximum.	Minimum.	Mean.		Per square mile.	Depth.
1901.	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*	*Acre-feet.*	*Sec.-feet.*	*Inches.*
January	1,450	28	169	10,391	.76	.87
February	2,605	137	680	37,765	3.06	3.19
March	440	135	221	13,589	1.00	1.15
April	130	95	110	6,545	.50	.56
May	272	83	121	7,440	.55	.63
June	93	41	63	3,739	.28	.31
July	41	24	30	1,845	.14	.16
August	27	15	20	1,230	.09	.10
September	20	15	17	1,012	.08	.09
October	122	15	24	1,476	.11	.13
November	50	29	32	1,904	.14	.16
December	30	26	27	1,660	.12	.14
The year	2,605	15	126	88,606	.57	7.49
1902.						
January	51	24	28	1,722	.13	.15
February	120	38	37	2,055	.17	.17
March	378	63	99	6,087	.45	.52
April	99	48	66	3,927	.30	.33
May	48	30	39	2,398	.17	.20
June	29.5	13.5	20	1,190	.09	.10
July	17	7.5	11	676	.05	.06
August	8.5	6	7	430	.03	.03
September	6	4.5	5	298	.02	.02
October	10.5	5.5	7	430	.03	.03
November	80	7.5	19	1,131	.09	.10
December	68	16	32	1,968	.14	.16
The year	378	4.5	31	22,312	.14	1.87
1903.						
January	2,999	22	148	9,100	.67	.77
February	203	61	102	5,665	.46	.48
March	1,417	57	257	15,802	1.16	1.34
April	5,892	267	792	47,127	3.57	3.98
May	355	125	217	13,343	.98	1.13
June	125	62	95	5,653	.43	.48
July	58	35	43	2,644	.19	.22
August	35	24	29	1,783	.13	.15
September	34	21	25	1,488	.11	.12
October	32	20	24	1,476	.11	.13
November	26	22	24	1,428	.11	.12
December	26	22	24	1,476	.11	.13
The year	5,892	20	148	106,985	.67	9.05
1904.						
January	28.2	23	24.4	1,500	.11	.13
February	438	23	47.7	2,744	.21	.23
March	1,130	35	110.8	6,813	.50	.58
April	120	57	89.7	5,337	.40	.45
May	104	37	66.5	4,089	.30	.35
June	38	17.5	25.5	1,517	.11	.12
July	18	11	14.0	861	.06	.07
August	29	9.5	12.9	793	.06	.07
September	13.5	7.5	10.8	643	.05	.06
October	15.5	9.0	12.0	738	.05	.06
November	14.5	11.0	12.8	762	.06	.07
December	48	14.7	16.9	1,039	.08	.09
The year	1,130	7.5	37	26,836	.17	2.28
1905.						
January	108	18.5	36.6	2,251	.16	.18
February	3,010	34	466	25,880	2.10	2.19
March	11,130	142	1,222	75,140	5.50	6.34
April	474	206	329	19,580	1.48	1.65
May	540	193	278	17,090	1.25	1.44
June	182	63	139	8,271	.63	.70
July	109	56	83	5,103	.37	.43
August	55	33	42.8	2,631	.19	.22
September	35	28	31.4	1,869	.14	.16
October	32	27	28.8	1,771	.13	.15
November	97	29	44.7	2,660	.20	.22
December	50	37	40.1	2,466	.18	.21
The year	11,130	18.5	2,284	164,700	1.03	13.89

Estimated monthly discharge of San Gabriel River and canals at Azusa, Los Angeles County, 1896–1906—Continued.

[Drainage area, 222 square miles.]

	Discharge.			Run-off.		
	Maximum.	Minimum.	Mean.	Total discharge.	Per square mile.	Depth.
1906.	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*	*Acre-feet.*	*Sec.-feet.*	*Inches*
January	441	36	68.1	4,190	.307	.35
February	92	47	68.1	3,780	.307	.32
March	9,430	56	2,160	133,000	9.73	11.22
April	1,110	321	578	34,400	2.60	2.90
May	1,110	251	342	21,000	1.54	1.78
June	364	204	262	15,600	1.18	1.32
July	295	97	155	9,530	.698	.80
August	93	57	72.8	4,480	.328	.38
September	55	42	47.7	2,840	.215	.24
October	42	38	39.8	2,450	.179	.21
November	47	37	40.4	2,400	.182	.20
December	1,600	45	188	11,600	.847	.98
The year	9,430	36	335	245,000	1.51	20.70

AZUSA IRRIGATING COMPANY.

The Azusa Irrigating Company was organized and incorporated August 23, 1886, by a part of the Azusa "old settlement" irrigators. The company was capitalized at $60,000, divided into 4,000 shares with a par value of $15 each, but the capital has since been increased to $180,000. Of the 12,000 shares, 10,865 have been issued and are distributed among 199 shareholders. They are reported to have a market value of about $35 each. The basis of the distribution is three shares to the acre. Delinquent stock reverts to the company and may be reissued, but only to lands within the Azusa water district established by the compromise of 1889. This district includes 5,508 acres, of which 4,043 are covered by the Azusa Irrigating Company and 1,465 acres are under contract by the Covina Irrigating Compay.

Water is prorated to stock and is distributed in 100-inch heads, which during times of abundant supply are given twelve-hour runs to each 10-acre tract in turn. When the supply becomes short, the time in each run is reduced.

The company owns the Azusa ditch, the oldest of the east-side canals, and other canals and pipe lines aggregating about 40 miles. The main canal is about 3 miles in length from the Azusa ice house, where the Covina and Azusa waters are divided, and this main line is extended 1½ miles beyond the terminus of the canal by a 30-inch vitrified pipe. The main distributing lines consist of 10-, 12-, and 14-inch cement pipe, according to grade, and are designed to carry 120 miner's inches. A reservoir with a capacity of 6,500,000 gallons and capable, therefore, of impounding a continuous flow of 800 miner's inches for fifteen hours, forms a part of the system. It was built in 1893 at a cost of $13,000.

In addition to the rights of the San Gabriel waters and the distributing system mentioned above, the company owns 40 acres of land in San Dimas Wash. Wells were sunk on this property, a pumping plant was installed, and a pipe line 4½ miles in length was laid due west to the main ditch, but the plant was sold later. Nevertheless, much pumped water is used in the district during seasons when the supply of gravity water is low. The Glendora and Azusa Water Company supplies the upper part of the district, and the lower part receives water from the Irwindale wells, operated by the Irwindale Land and Water Company, the Orange Avenue Water Company, and the Cypress Avenue Water Company. The majority of the stockholders in these subsidiary companies are also stockholders in the Azusa Irrigating Company.

Water rates are collected on the basis of a sliding scale, charges varying from $1.20 in February to $5.40 in July, August, and September for a twelve-hour run of a 100-inch head. The winter and spring charges, when water is abundant, are intended to be only nominal and merely to cover the zanjero's fees.

COVINA IRRIGATING COMPANY.

The Azusa Water Development and Irrigating Company, whose name was changed later to the Covina Irrigating Company, was incorporated May 20, 1882, capitalized at $5,000, and 6,667 shares of stock were issued at a par value of 75 cents per share. As its works were extended the capital stock of the company was increased at various times, and finally, in October, 1886, it was organized on its present basis of 10,000 shares at $50 per share.

The original company was organized to develop the underflow of San Gabriel Canyon and furnish a water supply for summer irrigation when the surface flow is low. In fulfillment of this purpose the tunnel, which cuts through two rock points in a crooked part of the canyon, about a mile above its mouth, was undertaken in 1882 and completed in 1889. This work, about 2,200 feet in length, in connection with a bed-rock dam below its upper section, delivers about 137 miner's inches, which amount, it was claimed by the promoters of the enterprise, had been developed by their work. This position was contested by other companies holding rights to San Gabriel waters, and the matter was not settled until in the compromise of 1889 one-tenth of the combined natural and developed flow of the canyon, so long as this was 1,700 inches or less, was awarded to the Covina Company.

On August 1, 1898, the salvage, which had been construed as belonging to the San Gabriel Power Company, whose canal above the power house had effected the saving, amounting to one-tenth of the total flow at the point of diversion 7 miles above the power

house, after 200 inches had been deducted, was purchased by the Covina Company for $66,500. In addition to water from these two sources the company receives the share of certain old users, whose interests aggregate about one-tenth of the flow of the canyon, and delivers this water to its owners at the rate of about 1 inch to 8 acres. About 1,465 acres are irrigated under this contract. When the total flow of the San Gabriel is 2,000 inches, the Covina Irrigating Company receives a total of 593.72 inches, consisting of company water, 210.7 inches; San Gabriel power water, 180 inches; and "old users" or contract water, 203.02 inches.

Like many other irrigating enterprises previously dependent on mountain water for a supply, the Covina Irrigating Company found during the dry years of the late nineties that its gravity water was insufficient for its needs and it was forced to resort to pumping. With this contingency in view, 104 acres of land one-half mile south of Lordsburg had been purchased for $20,000 on November 25, 1896. During 1898 and 1899 ten wells were bored on this property, a 100-horsepower steam engine and compressor were installed (Nos. 200–201) at a cost of $14,000, and a 12- and 16-inch pipe line was laid westward 6 miles from the pumping plant to the main canal.

March 21, 1899, 40 acres of water-bearing land were bought in San Dimas Wash for $10,000. A well (No. 242, Pomona quadrangle) was sunk shortly afterward on this property, equipped with a steam and air plant at a total cost of $5,000, and a 16-inch pipe line was laid to connect this plant with the system. Later in 1899 several hundred acres additional were purchased in San Dimas Wash at an outlay of about $15,000. In 1900 a plant (No. 230, Pomona quadrangle) was installed on this property, and connections with the system were effected. A further extension of the pumping system was made in 1904 by the addition of a small gasoline engine as an auxiliary to the Lordsburg plant.

The volume of this pumped water varies with the seasons, since it is used only to augment the canyon flow. During the summer of 1904, following an unfavorable winter, San Gabriel River was very low, and the pumping plants were in operation for a longer period than during any previous season. The following statement summarizes these operations:

Operations of Covina Irrigating Company's pumping plants, 1904.

No. of plant.	Time operated.	Average yield.	Cost per hour-inch.
	Days.	*Inches.*	*Cents.*
200–201	224	90	1.4
200–201, gasoline adjunct	12	30	
230	139	25	2.13
242	115	37	2.65

During this season the volume of pumped and canyon water delivered by the Covina Irrigating Company was as follows: Company water, 66,483 hour heads (25 miner's inches), equivalent to 189.75 inches continuous flow; contract water, 24,375 hour heads, equivalent to 69.6 inches continuous flow; alien water, 4,432 hour heads, equivalent to 12.6 inches continuous flow.

The company owns 5½ miles of the original Azusa Water Development and Irrigating Company's canal, built in 1885 at a cost of $40,000. This canal is cement lined, averages 4 feet in depth, and is from 4 to 8 feet wide. It ends in a 15,000,000-gallon cement-lined reservoir, located about 1 mile northeast of Covina. This reservoir was built in 1887 at a cost of $13,000. In addition to the canal and reservoir, which form the main artery and regulator of the system, there are nearly 1,200 feet of 16-inch, over 60,000 feet of 12-inch, 44,200 feet of 10-inch, and 1,500 feet of 8-inch cement mains and distributing pipe.

The stock of the Covina Irrigating Company is practically all held by landowners, although it is not appurtenant to the land and there is no provision in the charter prohibiting outside ownership. Nor is there any restriction as to the number of shares that may be acquired per acre, the irrigator being free to purchase as much stock as he thinks he needs. It is said that this condition occasionally results in abuse, and that a certain amount of trickery sometimes appears in the practical operation of the system. For instance, a part of the water stock pertaining to a given tract may be sold, leaving the property without a sufficient water supply. The land with the remaining stock may then be sold to some outsider who is not familiar with local conditions and who believes that he is buying enough water to irrigate his acreage.

All of the company water, gravity and pumped, is apportioned to stock, independent of acreage, and is distributed in rotation by schedule. Usually in midsummer a 25-inch head is given a six-hour run to each 10 acres, but a 50- or 100-inch head may be used at the option of the irrigator. The regular charge for delivery is at the rate of $2.50 per 100 inches for a twelve-hour run, and the annual water charge therefor is from $1.25 to $1.50 per acre. In addition to this, stock is assessed for whatever expense there may be in operating and maintaining the system in excess of the water receipts. This annual assessment varies from $2 to $3.50 per share. In 1904 water collections amounted to $5,126 and stock assessments to $30,000. There are 243 stockholders in the company, and water is delivered to about 350 irrigators, including the contractors. Many of the latter are stockholders also.

There are about 3,000 acres under the Covina system, but as an indefinite part of this acreage is supplied with water from outside

sources, it is not possible to state just the area irrigated by the Covina Company. The Citrus Belt Water Company supplies accessory water to the upper part of the district, between Glendora and Azusa, and the Columbia Water Company to the lower lands in the neighborhood of Covina. Most of the stockholders in these companies hold stock in the Covina Irrigating Company also.

AZUSA AGRICULTURAL WATER COMPANY.

In 1887 J. S. Slauson, J. D. Bicknell, and others, owners of 4,500 of the 5,000 acres in the Azusa ranch, combined these lands and the waters belonging thereto, forming an organization under the name of the Azusa Land and Water Company. The next year the Azusa Agricultural Water Company was organized with 6,000 shares, of a par value of $100 each, and the water rights of the Azusa Land and Water Company were transferred to it. Two shares of stock in the water company were conveyed with each acre of land sold by the Land and Water Company.

The rights of these companies, which depended on those of Mr. Dalton, former owner of the Azusa ranch, were not definitely settled until by the compromise of 1889 they were awarded $\frac{99}{720}$ of the total San Gabriel flow up to 1,700 inches, and $\frac{73}{720}$ of the excess over this amount. This apportionment, like that of all the other claimants to San Gabriel waters, has since been altered by the award of one-tenth of these waters to the San Gabriel Power Company as salvage.

The San Gabriel Canyon waters of the Azusa Agricultural Water Company reach the Azusa district through the Azusa canal, which carries the water of the Azusa Irrigating Company also. The division is effected at a point about one-quarter of a mile southeast of the Azusa ice house, where the water of the Azusa Agricultural Water Company enters its own system. This system, by means of which 900 acres, chiefly in oranges and lemons, are irrigated, includes about 4 miles of open cement flume 12 by 14 inches, and 4 miles of 8-, 10-, and 14-inch cement pipe. A reservoir with a capacity of 1,000,000 gallons has been built at a cost of $2,000.

The canyon water of this system has been supplemented by pumped water, a well (No. 255, Pomona quadrangle) just within the mouth of San Gabriel Canyon having been sunk in 1901 and equipped with a 30-horsepower electric motor at a total cost of $5,000. The water is pumped into the main canal and is taken out with the rest of the Azusa Agricultural Water Company's water, one-quarter of a mile southeast of the Azusa ice house. About 50 miner's inches are reported to be developed by this well. During the spring of 1905 another well was sunk in the wash, about one-half mile below the mouth of the canyon, and 8,440 feet of 16- and 20-inch cement pipe were laid to connect with the Azusa irrigating ditch above Azusa.

The water supply of this company is prorated to stock and distributed at intervals of four to six weeks. The domestic supply for the city of Azusa is taken from the Azusa Agricultural Water Company's share of the San Gabriel water, and in addition 39 families outside the town are supplied with domestic water.

CITRUS BELT WATER COMPANY.

The Citrus Belt Water Company was organized in 1900 by a number of irrigators in the district south and southwest of Glendora. They were owners of stock in the Covina Irrigating Company, who desired to supplement their portion of canyon water with pumped water. The capital stock of the new company was fixed at $35,000, divided into 500 shares with a par value of $70. Two hundred and thirty-five shares have been issued.

In the fall of 1900 the company purchased 42½ acres in San Dimas Wash, 5 or 6 miles from the lands of the stockholders, sunk a well, and installed a pumping plant. This plant consists of a 105-horsepower steam engine and centrifugal pump, and its capacity is given as 75 miner's inches. The cost of installation was $4,000. About 8 miles of 10- and 12-inch cement pipe, costing $9,000, and a reservoir costing $1,050 constitute the main distributing system. The water is delivered to each irrigator in turn in 25- or 50-inch heads, at intervals of two weeks. It costs the stockholders, of whom there are 43, about 2½ cents per hour-inch. The investments of the company is summarized by its officers as follows:

Property of Citrus Belt Water Company.

Land, 43½ acres	$10,000
Cement pipe, 3 miles 12-inch, 5 miles 10-inch	9,000
Pumping plant, 105 horsepower	4,000
Reservoir	1,050
	24,050

COLUMBIA LAND AND WATER COMPANY.

The Columbia Land and Water Company, like the Citrus Belt Company, was organized by stockholders of the Covina Irrigating Company to supply pumped water to their lands at times when the canyon flow is low. The company was organized in April, 1899, and capitalized at $60,000, divided into 600 shares. Twenty acres of land were acquired in San Dimas Wash, with two wells and pumping plants (No. 241, Pomona quadrangle) and several miles of pipe line. Each pumping plant is equipped with a 30-horsepower gas engine and centrifugal pump. The initial combined capacity of the two is given as 50 inches, which falls to 30 inches as the water level declines with continuous pumping. The pumps are operated twelve hours per day and about five months of each year, from June until the

beginning of the rains. A full head is used in irrigating and is charged for at the rate of $1 per hour, which, inasmuch as the amount of water in a head varies, equals 2 to 3 cents per hour-inch. The distributing system includes a reservoir built in 1904, and about 5 miles of 8- to 12-inch main, extending from the wells to the reservoir, 1 mile northeast of Covina.

The company's investment is as follows:

Property of Columbia Land and Water Company.

Wells and pumping plants	$3,700
Pipe lines, 5 miles	5,000
Reservoir	2,500
Real estate	1,000
	12,200

WESTERN WATER AND POWER COMPANY.

The predecessor of the Western Water and Power Company, the Glendora Water Company, was organized in 1887, with a capital stock of $62,500, divided into 1,250 shares, the par value being $50 each. Lands were acquired at once in Big Dalton Canyon, which gave to the company the control of all of this canyon and its water rights except 120 acres with the water pertaining thereto. This amount belonged to the Mountain Base Water Company until 1888, when it was purchased by the Glendora Water Company for $5,000, thus placing in the latter company complete control of Big Dalton Canyon and all its water rights. From 1887 to 1898, inclusive, the capital stock of the company was paid up in full and the money expended in improvements and betterments, approximately as follows:

Expenditures of Glendora Water Company.

Lands and riparian rights	$10,000
Reservoirs, 3; combined capacity, 2,500,000 gallons	8,000
Puddle dam in Big Dalton Canyon	8,000
Tunnel (1,200 feet) in Big Dalton Canyon for developing water	14,000
Supply pipe (8-, 10-, and 12-inch) for conducting waters from Big Dalton Canyon to Glendora and vicinity	10,000
Distributing pipe (12 miles, 1½- to 4-inch) for distributing water in Glendora	13,000
	63,000

During the trying years from 1897 to 1900 the Glendora Company, like the majority of southern California water companies, found its gravity supply insufficient to maintain the acreage already under irrigation, and it became necessary to resort to pumping. In 1901 160 acres were purchased in San Dimas Wash, in which several successful wells had already been located; two 12-inch wells (Nos. 232 and 233, Pomona quadrangle), each about 500 feet deep, were bored,

and a 250-horsepower pumping plant was installed and connected with a No. 6 centrifugal pump in each well. A 14-inch pipe line was then laid from the wells to connect with the Dalton Canyon line, 5 miles away. The wells produce about 125 miner's inches. These additions to the system were effected by means of a loan of $41,500 negotiated in 1901, the company's property serving as security. The details of the expenditures are about as follows: Land, $20,000; wells, $5,000; pumping plant, $10,000; supply pipe, $7,000. From 1901 to 1904 about $20,000 additional was expended on the pumping plant and branch pipe lines, and a considerable reduction was made in the company's indebtedness. As the expenditures and the value of the property owned exceeded the capital stock of the Glendora Water Company by a large amount, a reorganization seemed desirable. This was effected in April, 1904, by a sale of the company's property to the Western Water and Power Company, of Chicago, Ill. The capital stock of the newer organization is fixed at $100,000, divided into 1,000 shares whose par value is $100 each.

Since this sale the Western Water and Power Company has bought out the Alosta Water and Development Company, consisting of lands that control the water rights of Little Dalton Canyon and a system of pipe lines from this canyon to Alosta, just south of Glendora. Thus the present organization owns all the gravity water from Big and Little Dalton canyons and the pumping plant in San Dimas Wash. The gravity water is used when it is available; during favorable years it is sufficient to supply the system until after June 1, and yields a portion of the water required until a later date. The pumps are operated during the summer and fall.

Water rights have been sold to purchasers at 2½ and 4 cents per hour-inch. The rights have no relation to the lands, except that many of the large stockholders in the company are also large landowners under the Glendora system, so that their interests are identical.

GLENDORA-AZUSA WATER COMPANY.

The Glendora-Azusa Water Company was incorporated August 29, 1898, and capitalized at $48,450, divided into 484½ shares with a par value of $100 each. In 1898 170 acres of land were purchased in San Dimas Wash, at a cost of about $6,000. In 1900 a pumping plant was installed, and in 1902 a second well was sunk and equipped with pumping machinery. Centrifugal pumps are used in both wells (No. 231, Pomona quadrangle), a 75-horsepower motor running one and a 100-horsepower motor the other. The water is conducted from the wells through 10 or 11 miles of concrete pipe line to the lands served, lying west of Glendora, and distributed there. The system also includes one small reservoir with a capacity of about 200,000 gallons.

This is one of the systems developed partly to supplement the flow from San Gabriel Canyon, a part of the lands served lying below the Azusa and Covina canals and receiving gravity water from them. The pumping season of the Glendora-Azusa Company, therefore, varies with the supply of gravity water, being shortest during seasons of greatest rainfall. From 500 to 1,000 acres are wholly or partially supplied with water, which is distributed at a cost of 2½ cents per hour-inch. The average output during the season of 1905 is given at something less than 100 inches.

IRWINDALE WATER COMPANIES.

In the lower part of the Azusa water district, near Irwindale, three companies have been organized and pumping plants have been installed to develop underground water to serve as a supplement to the San Gabriel Canyon water. These are the Orange Avenue Land and Water Company, the Irwindale Land and Water Company, and the Cypress Avenue Land and Water Company.

ORANGE AVENUE LAND AND WATER COMPANY.

The Orange Avenue Company was organized in September, 1902, with a capital of $4,500, divided into 300 shares, distributed among 18 stockholders, all landowners. The plant consists of a well (No. 82, Pomona quadrangle) equipped with a 75-horsepower steam pumping plant. There is no pipe line, water being distributed to the stockholders directly or through the system of the Azusa Irrigating Company. The water costs the stockholders 1.55 cents per hour-inch, and is sold to outsiders for 3 cents per hour-inch. Distribution is effected in 25-, 50-, or 100-inch heads, as desired. About 380 acres are reported to be under irrigation.

IRWINDALE LAND AND WATER COMPANY.

The Irwindale Land and Water Company was incorporated September 19, 1899, and capitalized at $5,000, divided into 500 shares, which are distributed among 21 stockholders. Soon after organization one-tenth of an acre of land was purchased close to Irwindale, a well was sunk (No. 83, Pomona quadrangle), and a pumping plant was installed upon it. The plant consists of a 30-horsepower steam engine and Worthington pump, and its capacity is given as 60 inches. The output is pumped into the Azusa Irrigating Company's system and distributed through it. Distribution is effected in full heads, each share of stock being entitled to one hour's run monthly. The charge to stockholders is 2 cents per hour-inch, and to outsiders 3 cents per hour-inch. The water is used only to supplement the cheaper canyon water.

CYPRESS AVENUE WATER COMPANY.

The Cypress Avenue Water Company was organized in 1900 with a capital stock of $10,000, divided into 400 shares having a par value of $25 each; 202 shares have been subscribed for. The company operates a plant (No. 92, Pomona quadrangle) equipped with a 125-horsepower steam engine and centrifugal pump, reported to produce 113 inches of water. An independent steel pipe line, 1,300 feet in length, is also owned by the company. About one-half of the water is pumped into the Azusa Irrigating Company's system and the other half is distributed directly to stockholders. The water costs stockholders 1 cent per hour-inch; a charge of 3 cents per hour-inch is made to outsiders. All the members are stockholders in the Azusa Irrigating Company.

VINELAND IRRIGATION DISTRICT.

The Vineland irrigation district was organized in 1891, to include 4,000 acres in the vicinity of Vineland, just east of San Gabriel Wash. It claimed certain rights to San Gabriel Canyon waters, and these rights were sold with the land in the district. In the disputes which followed, however, the rights claimed by the district were given up in return for the installation of a pumping plant by the San Gabriel Power Company on a well which had been sunk by the Vineland irrigators on their tract. Such irrigation as is carried on in the district now depends on developed water from this plant, and inasmuch as the soil is sandy and porous and requires a large amount of water, and pumped water costs from 2 to 2½ cents per hour-inch, it has not been found practicable to irrigate vineyards or deciduous fruits. About 120 acres of citrus fruits, walnuts, and vegetables are irrigated, and perhaps 80 acres more are under cultivation.

An open stone ditch about 12 by 18 inches in size extends from the mouth of San Gabriel Canyon to a point 1 mile north of this district. This ditch catches some water from the Azusa ice-house waste ditch in winter, and this water is sometimes used by the Vineland irrigators.

DUARTE WATER COMPANIES.

RIGHTS.

The Duarte district is supplied with water by the Duarte Mutual Irrigation and Canal Company and the Beardslee Water Ditch Company. The upper part of the tract, consisting of about 1,000 acres, principally in citrus orchards, receives water from the former company. This area lies close to the base of the San Gabriel Mountains, on the sloping bench lands northwest of San Gabriel Wash. It extends from northeast to southwest a distance of 3 miles, and ranges in width from three-eighths of a mile at the eastern extremity to 1¼

miles on the west. The Beardslee Water Ditch Company serves about 400 acres of alluvial lands lying above San Gabriel Wash and adjoining the Duarte district on the west and south.

It is claimed that the rights of the Duarte irrigators to San Gabriel River water date back to 1854, when Andrés Duarte, the owner of the rancho, constructed a ditch and diverted a part of the San Gabriel flow to the west side. In 1859 or 1860, N. Beardslee acquired a part of the Duarte ranch by purchase, with the right to take water from the river for irrigation, and in the later year constructed a branch ditch to the lower Duarte neighborhood.

In 1872 Alexander Weil succeeded to the ownership of the Duarte interests, subdivided a part of the ranch, and sold off numerous small parcels along the upper part of the ranch, close to the base of the mountains, with rights to the Duarte ditch waters. In 1875 Mr. Beardslee sold several small tracts with rights to his share of river water, and in 1881 the purchasers of his lands and water rights organized and incorporated the Beardslee Water Ditch Company. In February, 1882, the property owners who had succeeded to the water rights of the Duarte ditch incorporated the Duarte Mutual Irrigation and Canal Company. For several years the flow through the joint ditch was divided equally between the two companies, but when the present works were built (1882–1887) and paid for by arrangement between the two companies in the proportion of 1,260 parts by the Duarte to 225 parts by the Beardslee company, the latter released to the former one-third of its one-half interest, so that two-thirds of the water right and works are now owned by the Duarte Mutual and one-third by the Beardslee company. Originally the two companies claimed one-third of the total flow of San Gabriel River. In the compromise agreement of 1889, by which all claims to the river water were adjusted, the Duarte companies were given title to three-tenths of the flow, surface and developed, when the total is equal to or less than 1,700 inches and $\frac{160}{720}$ of all excess over 1,700 inches.

In 1898 the San Gabriel Power Company acquired by right of salvage one-tenth of the total canyon flow, less 200 miner's inches, and disposed of this interest to the Covina Irrigating Company. Since this right was acquired, the total flow minus the above-mentioned proportion of salvage water has been divided as stipulated in the compromise agreement. As the flow of the San Gabriel fluctuates with the seasons and the rainfall, the supply of gravity water available for the use of the Duarte and Beardslee irrigators varies greatly in volume. During the irrigating seasons following dry winters, their combined share of San Gabriel River water sometimes falls as low as 75 inches. The maximum received is about 600 inches.

The Duarte and Beardslee irrigators claim and utilize the water of Fish Creek when the flow from that source is of sufficient volume to

reach their system. This occurs only during the rainy season. The waters of Fish Creek after the winter storms are clearer than those of the San Gabriel and are preferred and taken, for at that season the use is confined for the most part to domestic service.

JOINT WORKS.

The Duarte and Beardslee share of the San Gabriel water is taken out from the main associated water companies' canal at the San Gabriel Power Company's station a short distance below the mouth of the canyon. The water is conducted westward across the old east-side gravel wash to the main river channel through a 30-inch wood pipe, 1,000 feet in length, and a bowlder and cement lined ditch 1,500 feet long. The river crossing is effected by means of a steel siphon 24 inches in diameter, sunk deep below the bed of the river and cased heavily in cement and rock. From the river channel westward to the point of division between the two companies, the work consists of 2,700 feet of rock-paved and cemented ditch, 1,200 feet of brick-lined culvert, and 1,300 feet of 26-inch cement pipe. The entire conduit from the point of diversion at the San Gabriel power house to the division box, near the east end of the Duarte tract, is about 1¾ miles in length and cost $15,000.

DUARTE MUTUAL IRRIGATION AND CANAL COMPANY.

The Duarte Mutual Irrigation and Canal Company was incorporated in February, 1882, and capitalized at $12,590, divided into 1,259 shares, the par value being $10 per share. The capital stock has not been increased, but the market value of each share is now about $100. The stock is transferable and not appurtenant to the land, but practically all of it is held by landowners.

Water is delivered to stockholders only, and is divided on the principle of measurement of time in proportion to holdings of stock—that is, if the owner of 20 shares is entitled to a run of one head for twenty-four hours, the owner of 30 shares is entitled to a run of one head for thirty-six hours. The regular irrigating head used is 35 inches, but the period of rotation varies with the amount of water available. When the supply is low the division is made on half time, and an irrigator who would ordinarily be entitled to a run of twenty-four hours receives water for only twelve hours. There is no charge for the water as such, but the running expenses of the company, which include zanjero's and secretary's fees and maintenance charges, amount to about $1 per acre per year. Betterments and interest on indebtedness and payments on principal are met by separate assessments, which have been as high as $9 per acre annually.

In 1900–1901 this company bought an acre of ground in the eastern part of the district, sunk a well (No. 73, Pomona quadrangle), and installed a 60-horsepower steam engine and Wigmore pump, at a cost of $17,000. The capacity of this plant is stated to be about 60 inches, and the water delivered costs the irrigators 1⅓ cents per hour-inch. In 1904 another well was sunk above the first plant and adjoining the company's main pipe line. This well is 133 feet in depth, and a 4 by 6 foot tunnel has been driven horizontally from the bottom of the shaft for a distance of 125 feet into the gravels. The well is equipped with a 60-horsepower gas engine and a No. 6 centrifugal pump. The cost of the plant was $10,000. These two wells are used to supply accessory water during periods when the canyon flow is low.

The main distributing system of the Duarte Company, below the point of division between it and the Beardslee Company, consists of a 3,000,000-gallon reservoir which cost $5,000, and two main cement conduits, each about 2½ miles long. The upper conduit is 22 inches in diameter and the lower 16 inches. These lines, together with the distributing laterals, cost $15,000. About 1,000 acres are under irrigation.

BEARDSLEE WATER DITCH COMPANY.

The Beardslee Water Ditch Company was incorporated in September, 1881, with a capital stock of $2,250, divided into 225 shares. In 1884 this was increased to $20,000, divided into 630 shares. The market value is reported to be about $100 per share. This company, as has been stated, receives one-third of the west-side San Gabriel waters and one-third of the flow of Fish Creek, and in addition to maintaining its own canals and reservoirs, assumes one-third of the expense of maintaining and repairing that part of the west-side system, which it owns jointly with the Duarte Mutual Irrigation and Canal Company.

Below the point of division between the two west-side companies the water of the Beardslee Company is conducted through 3 miles of 12- and 14-inch cement pipe to a reservoir above the company's lands. This reservoir has a capacity of 2,000,000 gallons, and was constructed in 1898 at a cost of $7,500. Below the reservoir the company owns about 1¾ miles of distributing pipe. Other laterals have been laid by stockholders at their own expense, and the company water is distributed largely through these private lines.

The available water is divided into two heads, and each share is given a run of one head for fifteen minutes each week. The company has no zanjero, but each irrigator has a schedule giving the exact time when he may use the water, and when the proper time comes he himself turns it on.

The company has no accessory pumping plants, and its expenses are light, so that the annual cost of the water to the users is only about $1 per acre. The crops raised are diversified, and include citrus and deciduous fruits, alfalfa, and garden products.

MONROVIA WATER COMPANY.

The surface flow from Sawpit Canyon, which discharges into the San Gabriel Valley just north of Monrovia, was divided originally between the Bradbury and Santa Anita ranches. In 1886 the Monrovia Water Company was organized, and in 1887 it acquired the Santa Anita rights. Improvements were at once instituted in the canyon system, and on the basis of these improvements the company claimed and later obtained possession of four-fifths of all water flowing there.

The original conduit was a 20-inch cement line running into the canyon about half a mile from the reservoir at its mouth. Below the reservoir the water was distributed through 2 miles of 12-inch cement pipe laid along the Santa Anita-Azusa grant line. After its purchase of the Santa Anita rights the Monrovia Water Company expended $60,000 in constructing pipe lines in Sawpit and one of its tributary canyons. About 17,000 feet of 6-inch, 10-inch, and 12-inch iron and steel pipe were laid in the two canyons and connected with the original cement line.

Finding that the canyon water was not sufficient to supply the needs of the city, the company bought 5 acres of land in 1898 for $1,700 on the Chapman ranch, 3½ miles to the west. Three wells were sunk on this property, an 80-horsepower steam and air plant was installed, a reservoir built, and a 12-inch pressure main laid eastward 5 miles to connect with the city system. The total cost of these improvements was about $40,000.

Originally the city of Monrovia sold water rights with the city property, but water is now disposed of independently of property interests, though none is distributed outside the city limits.

An average of 120 miner's inches is now distributed during the irrigating season, about two-thirds of it being used to irrigate 900 acres of land. The remainder is utilized as a domestic supply for 550 to 600 families. The irrigating water is distributed in 25-inch heads, each acre receiving this amount for not more than four hours during each interval of four or five weeks. Two cents per hour-inch is charged for this water.

SANTA ANITA COMPANY.

The Santa Anita Water Company was incorporated July 9, 1886, with a capital stock of $300,000, divided into 3,000 shares. The company was organized for the purpose of supplying water to the

Santa Anita tract of 3,000 acres, and stock was issued on the basis of one share per acre.

Originally controlling and utilizing one-half of the flow of both Sawpit and Santa Anita canyons, about the year 1890 the company entered into a contract with the city of Monrovia, by the terms of which it turned over to the city the control and use of the waters of Sawpit Canyon. It was stipulated in return that the city should supply those lands of the Santa Anita rancho that lie north of the south boundary of the city and east of an irregular line which conforms closely with its western boundary. The Santa Anita Water Company retained the half interest in the water and works of Santa Anita Canyon and undertook the delivery of water to stockholders west of Monrovia.

The works in Santa Anita Canyon were built jointly by the company and E. J. Baldwin, who owns one-half interest in the canyon waters. They consist of a low dam about half a mile above the canyon mouth, a short tunnel, the necessary gates and wasteways, and 1,800 feet of 20-inch cement pipe, leading to a partitioner, where the waters are divided between the joint owners. Below the partitioner are something more than 6 miles of 4-inch to 12-inch pipe, which serve as main conduit and distribution system.

The Santa Anita Company's share of this canyon water, stated by officers of the company to average about 25 inches during the irrigating season, is not sufficient to supply the needs of the irrigators, and a supplementary supply is procured from a well and pumping plant (No. 254, Pasadena quadrangle) belonging to E. J. Baldwin.

Canyon water is appurtenant to the Santa Anita tract, and is distributed only to shareholders, of whom there were nineteen in 1906.

BALDWIN SYSTEMS.

E. J. Baldwin holds in private ownership one-half the waters of Santa Anita and Little Santa Anita canyons, all of the flow from the ciénagas and artesian wells in the vicinity of Santa Anita, a part of the waters which rise in the moist lands above the Paso de Bartolo, and a number of pumping plants on the Santa Anita rancho, which are utilized as needed. The diversion works in Santa Anita Canyon have been briefly described in connection with the account of the Santa Anita Water Company, joint owner of the water, diversion dam, and main pipe line. The ownership in the Little Santa Anita water is shared with the Sierra Madre Water Company, and the works at the point of diversion are also jointly owned. These joint works consist of a tunnel 230 feet long at the head of the system, about one-third mile above the canyon opening, and a 10-inch cement pipe about 4,000 feet long which leads to a division box

where the waters are partitioned between the two interests. Below this partitioner a 6-inch concrete pipe about 2 miles in length conducts the Baldwin share of the water to the lands on which it is used. This share is reported to amount to 10 or 15 inches during irrigating seasons, which follow winters of good rainfall.

The springs and artesian wells are distributed along the upper side of the irregular ridge which extends from above Monrovia to Raymond Hill. This district has always been an area of moist lands, and has furnished irrigation water since the settlement of the country. On the Santa Anita rancho are about 12 artesian wells, and the moist-land waters are collected by means of open ditches and tile drains; the combined yield from these sources is given as about 80 inches during the irrigating season.

Pumping plants have been installed at wells Nos. 273, 480, and 481 (Pasadena quadrangle), and when these are in operation a very much larger amount of water is obtained, their combined capacity being reported by the owner at 250 miner's inches.

Just above the Paso de Bartolo and between Lexington Wash and San Gabriel River the rising waters which are characteristic of this section are collected in earthen ditches and conducted through these and some small wooden flumes to lands within the pass and on either side of Rio Hondo, where they are used for irrigation. The flow in these ditches sometimes exceeds 150 inches.

In the vicinity of Santa Anita about 1,200 or 1,400 acres are under irrigation by the Baldwin and Santa Anita systems. Citrus and deciduous fruits, grapes, and alfalfa are grown.

SIERRA MADRE WATER COMPANY.

The Sierra Madre Water Company was organized by N. C. Carter, owner of the Sierra Madre tract, in 1882. At first there were 1,100 shares, one share to each acre of land in the tract, and as the par value of each share was $10, the capitalization was $11,000. August 24, 1894, the capital stock was increased to 8,800 shares, with a par value of $10 each. The original water supply came solely from Little Santa Anita Canyon, one-half of the surface flow of which belonged to the Sierra Madre Company and one-half to the owner of the Santa Anita rancho. This supply proving unreliable during the summer season, a well (No. 258, Pasadena quadrangle) was installed in the eastern part of the tract in 1900 and connected with the company's distributing system. Two engines are installed at the well, a 25-horsepower Columbus to operate the lift pump, and a 30-horsepower to operate the force pump, which drives the water up the slope to the higher parts of the system. The cost of the well, pumping plant, and distributing pipes is estimated at $13,000. Meters are installed in the system, and the pumped water is charged for at the rate of 10 cents per 1,000 gallons.

PRECIPICE CANYON WATER COMPANY.

The Precipice Canyon Water Company was incorporated in 1887 by four individual owners of all of the water rights in Precipice or Eaton Canyon. The organization was effected on the basis of 12,500 shares, the par value of each share being $50. Each of the incorporators received a number of shares directly proportionate to his original rights in the canyon waters. Since the organization 2,500 shares have been sold in small lots to fifteen or twenty individuals, while the remaining 10,000 shares are held by four stockholders.

The company owns 3 or 4 miles of pipe line. Some of the stockholders own small reservoirs, but the company itself owns none.

The water is divided among the shareholders, each owner receiving an amount proportionate to his ownership of stock. This water, however, is not appurtenant to the land, and shareholders need not be owners of realty. An owner of stock may, therefore, grant his proportion of water to whomever he may choose. About 120 acres of citrus fruits are irrigated by the system, and perhaps 200 acres of grapes receive water during the winter and spring. The expense of maintaining the system is borne by assessments on stock. The average cost is said to be about 25 cents per share.

W. I. Allen, manager of the company, furnishes the following table of flow from the canyon for a part of 1904 and 1905:

Flow from Eaton Canyon, in miner's inches.

	1904.	1905.		1904.	1905.
April	98.36	150.00	September	5.05	.....
May	68 44	155.00	October	7.00	.....
June	27.58	150.00	November	10.05	.....
July	13.13	112.00	December	14.07	.....
August	6.35	[a] 60.00			

[a] Approximate.

LINCOLN AVENUE WATER COMPANY.

The Lincoln Avenue Water Company was incorporated March 26, 1896, and capitalized at $72,000, divided into 7,200 shares, whose par value is $10 each. The individual interests that had held the rights to which the company succeeded transferred these rights to the company and received stock in payment; 3,670 shares have been issued; and the market value in 1906 was given as $8 per share.

The company holds all the water rights of Millard Canyon above the falls except those of Saucer Canyon, a small tributary which joins the main canyon from the north. This right and that of Millard Canyon below the falls are owned by the Giddings family, the water being used on Mountain View Cemetery, about 1 mile south of the base of the mountains.

The 700 acres of the Lincoln avenue tract, the water rights in Millard Canyon, and other lands and water rights were acquired by the Pasadena Improvement Company in the middle eighties. An 8-inch steel main was laid from the point of diversion in the canyon out to the head of the tract, reservoirs were built, and distributing lines were laid. This company, however, was disincorporated in 1893, and the water rights and such lands as had not been sold were divided among the stockholders. In 1896, as already stated, the present company was formed, largely of interests formerly included in the Pasadena Improvement Company. There are 30 to 40 stockholders in the company, all of whom are owners of property in the Lincoln avenue tract of 700 acres. Water, however, is not appurtenant to the land, and provision is made in the by-laws for distributing water outside the tract if desired. It is estimated that there are about 150 acres under irrigation.

In 1902 the company sunk a well (No. 436, Pasadena quadrangle) and installed a steam pumping plant. This plant is in operation twelve hours daily during the irrigating season, and is reported to yield 25 miner's inches. The canyon flow is said to vary from 3 to 20 inches, and since it is lowest during the summer and fall, pumped water is the principal reliance for irrigation. Canyon water, which is used for domestic purposes and during the spring and early summer for irrigation, is distributed for 1 cent per 1,000 gallons or less, which is something less than half a cent per hour-inch. Pumped water costs 6 cents per 1,000 gallons, or about 3 cents per hour-inch.

The well and pumping plant cost about $10,000. In addition, the company owns about 1½ miles of 8-inch steel main and 5 or 6 miles of 2- to 6-inch iron distributing pipe.

SUNNY SLOPE WATER COMPANY.

The Sunny Slope Water Company was organized by the Sunny Slope Land and Water Company and incorporated January 7, 1895, with a capital stock of $140,000, divided into 1,400 shares. The entire capital stock was issued to the land company and land was sold thereafter with one share of water stock to each acre. The water is made appurtenant to the 1,400 acres of land within the Sunny Slope tract and can not be delivered by the company outside of this area. The company has the right to develop water on 100 acres of ciénaga land surrounding its pumping plant (No. 465, Pasadena quadrangle). This tract is a part of the long, narrow belt of moist lands which lie on the north side of the "dike" extending from Raymond Hill, northeastward toward Santa Anita Wash. In the Sunny Slope area about 40 wells have been bored at various times, but the majority of them were long ago abandoned. The first of these wells was put in during the decade between 1860 and 1870, but the maximum flow

is reported to have been obtained about 1890, at the end of the wet decade which included the winters of 1884 and 1887, with their exceptional rainfall. The artesian flow at that time is given as 140 inches, but has steadily declined since. During the irrigating season, while pumping is under way, the flow is now an inconsiderable amount.

In 1903 the Sunny Slope Water Company installed a centrifugal pump operated by a 20-horsepower motor. The plant, whose cost is given at $3,000, has a capacity of 70 miner's inches. The distribution system, built before the organization of the present company, includes an earthen reservoir, about 60 by 150 by 10 feet, and 4 miles of 4-, 6-, and 8-inch steel mains.

About 250 acres of orange and lemon orchard are irrigated by the company, and water is applied once annually to about 500 acres of vineyard. Water is distributed in 25-inch heads by schedule in rotation periods of six weeks, and is charged for at the rate of 7½ cents per miner's inch for a twelve-hour run.

CHAPEA WATER COMPANY.

The Chapea Water Company was incorporated July 22, 1896, and capitalized at $28,000, divided into 400 shares whose par value is $70 each.

During the year of organization the company purchased from Mr. Chapman, owner of the Chapman ranch, 40 miner's inches of water, paying therefor $500 per inch. At that time the water was artesian, but with increased drafts on the basin and the installation of pumping plants on adjacent wells, those from which the Chapea Company is supplied ceased to flow and a pumping plant was installed over them. The 40 inches furnished in 1905 werepumped. The company has no reservoir, but owns 4 miles of 10-, 6-, and 4-inch riveted steel pipe, laid in 1896 at a cost of about $8,000.

Each irrigator receives in a continuous flow during the irrigating season a share of the water proportionate to his holdings of stock. The irrigation is accomplished on the basis of 1 miner's inch to 5 acres. Two hundred acres planted to oranges are under irrigation. The total cost to the irrigators, including the salary of $60 per year which the secretary, the only paid officer of the company, receives, is $1,200.

GARVEY WATER COMPANY.

The Garvey Water Company was organized in 1892, and capitalized at $50,000, divided into 1,000 shares, with a par value of $50 each. The company owns a well and pumping plant (No. 58, Pasadena quadrangle) in the old artesian belt 1 mile northwest of North San Gabriel, and the water developed there is carried through about 6 miles of 8-inch steel main to a reservoir in the hills south of San Gabriel Valley, overlooking the Garvey tract, upon which the water is used.

This reservoir and main were constructed in 1892 at a cost, as given by the company's officers, of $31,000. The well is reported to have yielded 70 inches of gravity water at the time of purchase, but during the three years from 1903 to 1905 it was necessary to pump during the irrigating season, although the gravity flow at the point where the well is tapped, 20 feet below the surface, was sufficient for a domestic supply for the tract. A centrifugal pump and a 16-horsepower electric motor, supplied with power from Pasadena, are used when pumping is necessary.

About 200 acres are irrigated, the water costing the users at the rate of $2.50 for a ten-hour run of 30 miner's inches, or five-sixths of a cent per hour-inch. Each acre is given a two and one-half hour run of 30 inches monthly.

ALHAMBRA ADDITION WATER COMPANY.

The Alhambra Addition Water Company was incorporated in December, 1883, with a capital stock of $250,000, divided into 2,500 shares, of a par value of $100 each. The rights to the surface flow of El Molino Canyon, which cuts through the Raymond "dike" about 1 mile east of Raymond Hill, were purchased from the owner, and 50 inches of water were diverted. Up to 1905 ten wells had been sunk in the canyon, several of which are pumped by the 30-horsepower steam plant and air compressor that have been installed. The capacity of the plant is given by the company as 150 inches. A number of the wells are not connected with the pumping plant, but have been tapped several feet below the surface. The flow from these and from the canyon aggregated about 20 inches in the spring of 1905.

The company owns about 20 miles of distributing pipe from 4 to 16 inches in diameter, laid between 1876 and 1905, from the canyon to Alhambra. It also has constructed one 4,000,000-gallon reservoir, and three with a combined capacity of 2,000,000 gallons. It owns 27 acres of land—17 acres in El Molino Canyon and the balance in reservoir sites.

One thousand acres of land in Alhambra and vicinity are irrigated at an annual cost to the irrigators of $1 per acre. The water is delivered in 25-inch heads, at the request of irrigators.

EUCLID AVENUE WATER COMPANY.

The Euclid Avenue Water Company was incorporated December 24, 1900, with a capital stock of $25,000, divided into 2,500 shares, whose par value is $10 each. Its organizers are the owners of 165 acres constituting the Los Robles tract, and of a right to 17½ inches of water in Los Robles Canyon, a short distance east of the Raymond

Hotel. So far 1,325 shares have been issued; these are held exclusively by owners of realty in the Los Robles tract.

The first development work in the canyon was a tunnel which furnished a gravity flow. This flow ceased in 1898. In 1901, after the organization of the present company, a small tract of land was bought in Los Robles Canyon for $250, a well (No. 53, Pasadena quadrangle) was sunk, and a small pumping plant was installed. At the same time another small tract half a mile farther up the canyon was purchased. This tract is held in reserve. The well in use is equipped with a centrifugal pump, run by a 15-horsepower motor. It is reported that 26 inches of water are developed.

The company owns 1½ miles of steel distributing pipe and a reservoir of 1,000,000 gallons capacity. The pipe lines were laid and the reservoir constructed in 1891.

The 165 acres of the original tract are irrigated at a cost of $15 per acre per year, but no water is sold outside this tract. The water is distributed in heads of 40 weir inches, "Pasadena module" (equivalent to about 18 miner's inches), at intervals of approximately six weeks.

MARENGO WATER COMPANY.

The Marengo Water Company was organized December 27, 1884, on the basis of a capitalization of $250,000, divided into 5,000 shares, with a par value of $50 each. An area of 1,250 acres, comprising what was originally known as the Bacon ranch, but later was divided into the Raymond Improvement Company tract and the Marengo tract, is entitled to water, four shares of stock having been allotted to each of the original 1,250 acres.

The first source of water for this acreage was a series of springs which represented overflow from the Pasadena Basin across the Raymond Hill dike, but as these springs dried away the water supply was maintained by developments consisting of wells and tunnels along San Pasqual Wash to the north and west of Raymond Hill. The first tunnel was driven under the hills west of the Raymond Hotel in 1883, and for a time furnished a supply of about 20 miner's inches, but this flow dwindled and the tunnel is not now used. A later tunnel driven east of Raymond Hill into San Pasqual Wash furnishes a constant flow, which is given as 45 inches during the winter months and 30 inches during the summer months. In addition to this tunnel development the company has in use two 12-inch wells, located at the upper end of San Pasqual Wash, in the south end of the Pasadena Basin. An Ames pump driven by a gasoline engine and a Wood pump driven by electrical power constitute the equipment of these wells, which are reported to yield about 40 inches each.

The distribution system includes a covered and cement-lined reservoir 450 by 100 by 7½ feet, with a capacity of 2,500,000 gallons. There are a number of miles of pipe line from 2 to 10 inches in diameter and 220 meters representing domestic users. Only about 160 acres of the original tract are now under cultivation as agricultural lands, and these are planted to orange groves almost exclusively. The rate charged for water used in irrigation is $2 per day of ten hours for a head of 25 weir inches. For water used for domestic purposes $1.25 is charged for the first 1,300 cubic feet and 6 cents per 100 cubic feet for all in excess of this amount.

MONTEBELLO LAND AND WATER COMPANY.

The Montebello Land and Water Company was incorporated February 10, 1900, and capitalized at $125,000, divided into 1,250 shares, with a par value of $100 each. The company was organized for the purpose of supplying the Montebello tract of 1,250 acres, lying 3 or 4 miles southwest of the Paso de Bartolo, with water. One share of stock is issued with each acre of land sold. This share entitles the holder to a twelve-hour run of 7½ inches monthly, a rate of about 1 miner's inch to 8 acres. Extra water, which will be furnished if available after all regular orders are filled, is charged for at the rate of $8 for a twelve-hour run of 100 inches, or two-thirds of a cent per hour-inch.

The pumping station (No. 279, Pasadena quadrangle) which furnishes the water is situated on the mesa about one-fourth mile east of Rio Hondo and one-half mile north of the Los Angeles–Whittier road. It consists of six wells operated by two plants, a cross compound Corliss engine and centrifugal pump, and a Worthington engine and pump. These plants develop 110 horsepower and the company gives their capacity as 300 inches, with an output of 225 inches during the irrigating season. The tract of 1,250 acres lying west of the station has been piped with 4-inch and 6-inch steel distributing lines, of which 12 miles have been laid. Two reservoirs have been built whose combined storage capacity is stated to be 6,500,000 gallons. The total investment is summarized by the company's officers as follows: Wells and pumping plants, $35,000; pipe lines, $20,000; reservoirs, $3,000, total, $58,000.

Six hundred acres were under irrigation during the season of 1905. Berries, vegetables, citrus fruits, and walnuts are grown.

NORTH PASADENA LAND AND WATER COMPANY.

The North Pasadena Land and Water Company was incorporated in 1885 with a capital stock of $90,000, divided into 1,800 shares, whose par value is $50 per share. In 1880 J. H. Painter and B. F. Ball had acquired 1,800 acres of land on the east bank of Arroyo

Seco, beginning perhaps 1 mile below the mouth of the canyon and extending thence eastward and southward. At the same time rights to all water flowing in the main canyon above its lower tributary, Millard Canyon, were secured. In 1887 a 10-inch by 12-inch cement pipe something more than 2 miles in length was laid to the tract. This property was all turned over to the North Pasadena Land and Water Company after its incorporation, the former owners of the property receiving stock in payment. Land was then sold, with one share of water stock to each acre, and the control of the company passed into the hands of the landowners.

The old pipe line from the canyon to the company lands was replaced in 1893 by a vitrified-clay and steel main, ranging from 13 to 18 inches in diameter. The water from springs and small tunnels in the upper part of the canyon and its tributaries is collected and carried to the head of the main-canyon conduit through several miles of small iron pipe.

The total gravity flow from the canyon attains considerable volume during the winter and is usually sufficient for the needs of the tract during the spring and early summer, but has to be augmented by pumped water during the summer and fall. The average gravity flow during the summer months, July to November, 1904, following a dry winter, was 4.3 miner's inches. The following series of measurements, taken during the wet winter and spring of 1905, represent contrasting conditions:

Gravity flow from Arroyo Seco canyon, 1905.

	Miner's inches.		Miner's inches.
January 12	55	March 25	2,620
January 19	58	March 31	1,356
January 25	99	April 7	725.5
February 18	2,700	April 15	877.5

About 1895 this company, pursuing a policy forced on the majority of the water companies owning gravity systems in the southern part of the State at that time, prepared to develop underground waters, with which to augment the surface supply. Water-bearing lands were bought, and two wells were sunk (Nos. 435 and 437, Pasadena quadrangle) and equipped with pumping machinery. One of these (No. 435) is about half a mile north and half a mile east of Devils Gate, and is 160 feet deep. A 35-horsepower engine and deep-well plunger pump are installed. The other well (No. 437) is about three-fourths of a mile south of Devils Gate and but a few hundred feet east of the Arroyo Seco canyon. Originally 96 feet deep, it was sunk to 135 feet in 1904 in consequence of the lowering of the water plane. The well is evidently north of the bed-rock spur which extends from the banks of the arroyo toward Monk Hill and dams back the ground waters above it. The bottom of the shaft did not reach bed

rock, but probably closely approached it. The output of these two wells from July to November, 1904, is reported to have averaged 87 inches. The greater proportion of the water is furnished by the lower well, because as its lift is less it is operated more constantly.

The company reports that the cost of its pumped water during 1904 amounted to $2.78 per 1,000 gallons, or $48 per miner's inch per year. Irrigation water is supplied at 3 to 5 cents per hour-inch (miner's, not "surface" inch), the charge varying with the proportion of pumped and gravity water. The water is distributed in rotation in heads of 20 "surface" inches (about 9 miner's inches) at intervals of thirty days. The output is apportioned in proportion to holdings of stock. An area of 173 acres, belonging to 25 irrigators, is supplied by the company.

In addition to this irrigating water, domestic water was supplied in 1905 to 972 taps, at the following rates: One thousand cubic feet or less, $1.50; first additional 1,000 cubic feet, $1; each additional 100 cubic feet, 6 cents. The daily consumption of domestic water in 1905 was 1,065,000 gallons, and on the basis of four users to each tap, 3,888 people were served and the rate of consumption was 275 gallons per capita daily.

The company's pipe system includes the main-canyon conduit, 5,000 feet of 16- and 18-inch vitrified-clay pipe, 6,450 feet of 13-inch iron pipe, and about 26.2 miles of steel pipe from 1 to 14 inches in diameter in the distributing system. Two reservoirs, concrete and asphalt lined and roofed, also form a part of the system.

PASADENA LAKE VINEYARD LAND AND WATER COMPANY.

ORGANIZATION AND TERRITORY.

The Pasadena Lake Vineyard Land and Water Company was incorporated in January, 1884, with a capital stock of $250,000, divided into 5,000 shares, the par value being $50 per share. This company, spoken of generally as the "east side company," delivers irrigating and domestic water to Pasadena east of Fair Oaks avenue, and to lands outside of the city limits, eastward from Pasadena toward Lamanda. The greater part of the territory supplied lies within the boundaries of the original 2,500-acre Lake Vineyard tract, of the San Pasqual rancho. Consumers located within the limits of this tract can purchase water from the company without owning stock, but outside residents, in order to obtain water, either for domestic use or irrigation, must become shareholders. The area under irrigation in the Lake Vineyard tract is said by Wm. Ham. Hall to have reached 2,000 acres in 1884, but with the expansion of the city of Pasadena a large part of the orchards and vineyards which formerly covered this area have been divided into town lots, and streets have been cut

through to afford them frontage. As a result the area of irrigated lands has steadily diminished until at the present time it is estimated that the company supplies, within and without the original tract, a total of not more than 200 acres with irrigating water. By far the greater part of the revenues of the company is derived from the sale of domestic water within the city limits of Pasadena.

WATER SUPPLY.

The water supply of the Pasadena Lake Vineyard Land and Water Company is derived from wells and tunnels near Devils Gate, on the east side of Arroyo Seco, and from wells on the mesa near the reservoir at the head of the Lake Vineyard tract. The works and water rights at Devils Gate are owned jointly by the Pasadena Lake Vineyard Company and the Pasadena Land and Water Company in the proportion of seven-tenths to the former and three-tenths to the latter company. The Copelin and Banbury wells and pumping plants (No. 432, Pasadena quadrangle) are independent properties of the Pasadena Lake Vineyard Company.

HISTORY OF WATER RIGHTS.

In 1874 the Lake Vineyard Land and Water Association was incorporated and acquired 2,500 acres of the San Pasqual rancho, adjoining the San Gabriel Orange Grove Association's tract on the east, with a part interest in the springs immediately above and below Devils Gate. It was the object of the company to divide the tract into small lots, sell these, and grant to each purchaser an interest in the water, proportional to the amount of land purchased. The company's share of water was made appurtenant to the 2,500-acre tract, and a concrete-lined ditch 13,000 feet long was constructed to deliver water from the springs to a reservoir on the mesa at the head of the company's lands. Distributing pipe was laid from the reservoir, and lands under the system were sold, one share or a five-hundredth interest in the water being conveyed with each 5 acres of land, with the right to the use of the company's canal and pipe lines for delivery. In 1883, after having disposed of 1,500 acres of the 2,500-acre tract, the company sold an undivided tenth interest in its waters, and an undivided three-tenths interest in its water-bearing lands to the San Gabriel Orange Grove Association, and the remaining interests not disposed of to a syndicate of twelve residents of Pasadena. The original interests having thus become scattered with no strong central organization in control, no effective administration was possible, the canals and pipe lines were neglected, and the entire system deteriorated. Accordingly, the Pasadena Lake Vineyard Land and Water Company was organized in 1884 by a large majority of

the purchasers of land and water rights from the old association for the purpose of repairing the system and acquiring and developing a greater quantity of water. These granted to the new corporation their interests, and received therefor shares of the corporation stock, 10 shares being issued for each of the old 5-acre water rights. A few of the holders of the water rights purchased from the old association declined to join the new organization and did not convey their interests. The new company repaired the system and developed the springs, greatly increasing their flow. To enable this work to be carried out, assessments on stock amounting to $8.37 per share were levied. A definite water rate to stockholders was also fixed, the figure being made high enough to cover the cost of operation and of repairs. In 1885 suit was brought by the Lake Vineyard Land and Water Company to determine the ownership of water rights as between the old Lake Vineyard Association and the Orange Grove Association. This suit was subsequently compromised and the Pasadena Land and Water Company, which had succeeded to the rights of the Orange Grove Association, was given title to three-tenths of all the water of the Devils Gate springs, the Lake Vineyard Company retaining title to seven-tenths.

After the organization of the Lake Vineyard Land and Water Company, some of the holders of the original water rights who had remained outside of the corporation attempted to establish a pro rata interest in the water developed by the company by paying their share of the expense of operation. George W. Beck, one of those who had succeeded to $\frac{1}{250}$ of the original water rights, as appertaining to 2 acres, refused to pay the rate charged him for water by the company and applied for a permanent injunction to restrain the directors from discontinuing service in supplying him with his share of water. A decision was rendered by the State supreme court in December, 1889, defeating the plaintiff. In 1894 the parent organization, the Lake Vineyard Land and Water Association, was disincorporated.

DEVILS GATE JOINT WORK.

In 1887 the Pasadena Land and Water Company and the Pasadena Lake Vineyard Company joined in laying a 22-inch lapped and riveted steel conduit, to replace the old open ditch, from the Devils Gate springs to a point of division on the mesa at the main reservoir. About 1891 the two companies, finding the flow from the springs inadequate for their needs, began the construction of works to develop and bring to the surface the waters of the underflow of Arroyo Seco and the east-side mesa. About 1891, 2,008 feet of tunnel were constructed through the rocky point on the east side of Devils Gate into the east-side mesa and under the gravel beds of the arroyo. Beginning at the lower end of the gorge and passing northward into the

point of rocks for about 100 feet, the tunnel was divided into two branches, the right-hand branch taking a northeast course into the mesa a distance of 600 feet, and the left-hand branch a northwest course for a few hundred feet to a second fork. From this second dividing point another branch was continued westward and under the stream bed at the upper end of Devils Gate, while the main work was extended nearly due north about 1,000 feet under the bed of the arroyo close to the east-side mesa. In 1895 the main tunnel was extended from its northern extremity eastward into the mesa a distance of 2,529 feet. In 1902 two wells were sunk (Nos. 434 and 434a, Pasadena quadrangle) and a further extension of the tunnel of 337 feet was made to these wells. The tunnel tapped the wells at a depth of 175 feet from the surface. These wells flow and are pumped by compressed air into the tunnel. They have a depth of 375 and 575 feet, respectively. A third well has been sunk recently and is being connected with the tunnel.

In 1897 a submerged dam was built across the narrows at the upper end of Devils Gate, immediately below the west branch of the tunnel (Pl. II, *B*, p. 52). The underflow of the arroyo is held by this dam, while the tunnel taps the gravels and leads the water into the pipe system below. At the extremity of this branch on the west side of the stream channel an opening is provided for the admission of the storm waters. In 1897 a solid masonry dam was laid in the bed rock a short distance within the mouth of the tunnel, and a valve was constructed by which the tunnel can be sealed entirely or the flow partially cut off at will. As a result of closing the tunnel in winter the water plane in the wells above rises about 20 feet. That the general water plane in the area surrounding the wells is raised is evident also from the fact that an increased flow comes from the wells for weeks after the opening of the tunnel.

In 1903 a 100-horsepower compressed-air plant was installed at the mouth of the tunnel below Devils Gate. Compressed air is piped from this plant to the wells described above, and by its use water is raised to the tunnel level, whence it flows by gravity past the plant into the main conduit below. The gravity flow from the tunnels and wells varies with the seasons. The tunnels are partially sealed during the winter months, so that no measurements of the total flow are available. During the summer the pumping plant is in operation for a variable period, whose length depends on the previous winter's rainfall and the amount of gravity water available. During the summer of 1906 it was not found necessary to start the pumps at all, because of the copious rainfall of the two preceding seasons. Engineers who have studied the local situation thoroughly express the belief that if pumping operations were suspended for a considerable period of time the gravity flow would reach 100 miner's inches.

Records of measurements taken in 1904 of gravity and pumped water discharged from the tunnel and tunnel wells show on August 1, after the pumping plant had been shut down three hours, a gravity flow of 55.05 miner's inches; on the same day, after the plant had been shut down seven hours, a flow of 53.25 miner's inches; and on August 4, after a nine-hour shut down, a flow of 53.25 miner's inches. The officers of the company call attention to the facts that during the seven years preceding 1904 the rainfall had been low, and that periods of three to nine hours after closing the pumps may not be sufficient to allow the maximum flow to be reached.

OTHER WORKS IN ARROYO SECO.

In addition to the main work, three minor tunnels have been constructed and a pumping plant installed in the arroyo along the pipe line within half a mile of the mouth of the main tunnel. About 1889 a shaft (well No. 433, Pasadena quadrangle) was sunk close to the east bank of the arroyo, a few hundred feet below the mouth of the main tunnel, and a short tunnel was driven westward under the bed of the arroyo a distance of 288 feet. A pumping plant was placed over the shaft and equipped with a 12-horsepower gas engine and No. 4 centrifugal pump. This plant has a capacity of 25 inches for twelve hours. In 1894 a tunnel 575 feet long was driven eastward into the mesa at Wilson's Spring and another 665 feet in length at Richardson Springs. These works are located along the bank of the arroyo about half a mile below the main plant. August 1, 1904, the Wilson tunnel was flowing 3.79 miner's inches, and August 4, 1904, the Richardson tunnel was flowing 8.35 miner's inches.

INDEPENDENT PROPERTY.

Besides the Arroyo Seco properties, which are held in joint ownership with the Pasadena Land and Water Company, the Lake Vineyard Company has two independent wells and pumping plants (No. 432, Pasadena quadrangle). These are known as the Copelin and Banbury wells and are located on the mesa a short distance above the main reservoir. The Banbury well is not in active use at the present time, but in April, 1905, a 200-horsepower Corliss engine and a centrifugal pump were installed on the Copelin well, raising the normal output of the plant to nearly 200 inches.

DISTRIBUTION.

Water for irrigating purposes is delivered on orders filed at the office of the company and filled in succession. Water is distributed in heads varying in volume from 5 to 25 weir inches ("Pasadena module") and charged for at the rate of 1 cent per hour-inch. It is estimated that the company supplies about 200 acres with irrigating water.

Domestic water is metered and a charge of $1 is made for 600 cubic feet and 5 cents per hundred for each additional 100 feet. The company has 1,958 meters in use.

VALUE OF PROPERTIES.

October 15, 1904, T. D. Allin, city engineer, and Lippincott & Parker, consulting engineers, submitted a report to the city of Pasadena on the properties of the Pasadena Land and Water Company and the Pasadena Lake Vineyard Land and Water Company. In this report the works of each company are described in detail and a careful estimate is made of their present value. The following valuation is summarized from this report:

Summary of values of the property of the Pasadena Lake Vineyard Land and Water Company (east-side system) exclusive of real estate, water, and water rights.

	Cost, new.	Depreciation.	Present value.
Pipe system purchased prior to January 1, 1889	$22,897.24	$9,625.63	$13,271.61
Pipe system purchased since January 1, 1889	103,220.63	29,502.20	73,718.43
Meters purchased prior to June, 1900	15,384.30	3,846.08	11,538.22
Meters purchased since June, 1900	8,007.00	556.84	7,450.16
Air valves	78.00	24.36	53.64
Gate valves	3,536.48	636.57	2,899.91
Specials	1,527.04	546.71	980.33
Clamps	431.75	154.58	277.17
Bands	124.97	44.71	80.26
Banbury well	3,175.70	1,561.26	1,614.44
Copelin well	13,632.54	3,553.60	10,078.94
Reservoir No. 1, less three-tenths of division box	19,245.36	806.99	18,438.37
Reservoir No. 2	49,083.60	1,874.97	47,208.63
Dry tunnel, seven-tenths	2,377.44	.....	2,377.44
Wagon road and fence, seven-tenths	453.68	23.10	430.58
Office furniture	500.00	.....	500.00
Total value of construction work, including Banbury and Copelin wells and not including other water-development work	243,675.73	52,757.60	190,918.13
Add 20 per cent for engineering, administration, contractor's profits, etc	.....	.....	38,183.63
Value of the going business	.....	.....	13,500.00
			242,601.76

This is the estimated value of the property exclusive of the Devils Gate developments, property outside of the city of Pasadena, and real estate.

The engineers, in endeavoring to arrive at the value of the Devils Gate waters, concluded that the works there would deliver to the systems 100 inches of gravity water or 200 inches of pumped water, and under the conditions which existed in Pasadena at that time the gravity waters were valued at $2,000 and the pumped waters at $1,000 per miner's inch; so that whether the waters procured by the Devils Gate developments are regarded as the lesser amount at the higher valuation or the greater amount at the lower valuation is immaterial. The total value by either method of reckoning is $200,000. In this calculation the value of the works by which the

water is developed is included in the estimate. Since seven-tenths of the Devils Gate developments belong to the Pasadena Lake Vineyard Land and Water Company, its interest in the total amounts to $140,000. The city engineer, T. D. Allin, has estimated the value of that portion of the company's plant outside of the city of Pasadena at $18,531.95, and a special commission appraised the real estate at $34,816.97. The total valuation of the east-side company's property, therefore, may be summarized as follows:

Value of property of Pasadena Lake Vineyard Land and Water Company.

Plant in Pasadena (exclusive of Devils Gate interests) pipe system, reservoirs, going business, etc	$242,601.76
Seven-tenths interest in Devils Gate developments	140,000.00
Real estate	34,816.97
Portion of plant outside of Pasadena	18,531.95
	435,950.68

PASADENA LAND AND WATER COMPANY.

ORGANIZATION AND TERRITORY.

The Pasadena Land and Water Company was incorporated in March, 1882, with a capital stock of $50,000, divided into 200 shares with a par value of $250 each. In December, 1885, the capital stock was increased to $75,000 and the number of shares to 3,000, the par value of each share being reduced to $25.

This company, usually spoken of as the "west-side company," to distinguish it from the Pasadena Lake Vineyard Land and Water Company, known as the "east-side company," serves an area of about 1,500 acres, lying in a strip less than a mile wide and about 4 miles long on the east bank of Arroyo Seco. Two-thirds of this area is at present in the city of Pasadena, and one-third in the separate municipality of South Pasadena. Only about 100 of the original 1,500 acres are now under irrigation, the remainder being occupied by homes and users of domestic water.

WATER SUPPLY.

The water supply of the west-side company is derived from the Devils Gate developments, owned and controlled jointly by the east-side and west-side companies, title to three-tenths of the works and of the water developed being in the latter, from the Sheep Corral Springs developments, which belong exclusively to the west-side company, and from the Bradford street well, the Culver well, and the Glenarm street well.

The capacity of the Devils Gate developments is estimated at 200 inches of pumped water, and the west-side interest of three-tenths

of this amounts to 60 inches. The Sheep Corral developments have yielded 90 inches or more in the past, but, as this is regarded in excess of the permanent supply, the capacity of the works is placed at 50 inches. The Bradford street well yields 8 inches during the summer months, the Culver well yields about the equivalent of 10 inches constant flow, and the capacity of the Glenarm street battery of wells with present water levels is given as 90 inches. The total available permanent supply for the west-side company with its present installation, therefore, amounts to about 218 miner's inches.

HISTORY OF WATER RIGHTS.

In 1873 an association was formed at Indianapolis, Ind., under the title of the Indiana Colony, for the purpose of settlement in southern California. The association's representatives acquired 4,000 acres of land in two tracts, one of 1,500 acres along Arroyo Seco, and the other of 2,500 acres in the Altadena and Mesa de Las Flores neighborhoods. Title to all the waters at Sheep Corral Springs and to an interest in the waters about the Devils Gate was purchased with these lands. Only about twelve of the original Indiana colonists emigrated to California, but the uncalled-for shares were taken in Los Angeles and the general plan was carried through. The subscribers, of whom there were about thirty, then organized and incorporated the San Gabriel Orange Grove Association, with 100 shares, each share entitling the holder to a 15-acre subdivision of the lower 1,500-acre tract. The water rights and the 2,500-acre tract were not subdivided, but were held for the benefit of the association as a whole, and afterwards the latter tract was sold and the proceeds invested in improvements in the water system, etc.

A series of disputes between the east-side and west-side parties at interest as to the ownership of the waters in the springs about Devils Gate began in the seventies and was not finally settled until a compromise was effected in 1885. The first of these suits was decided in 1879 adversely to the interests of the Orange Grove Association. In July, 1883, the association bought from the east-side organization for $10,000 an undivided one-tenth interest in its waters and an undivided three-tenths interest in its unsold water-bearing lands and main conduit. By the terms of the compromise of 1885, these purchased interests were accepted as equivalent to a three-tenths interest in all the waters of all the upper springs, title to the remaining seven-tenths remaining in the east-side company. This adjustment has served as the basis for the distribution of all costs of improvements and maintenance, and for the division of all Devils Gate waters since it was effected. The Sheep Corral waters and water rights have never been in dispute, but have been acknowledged as the property of the west-side company since the predeces-

sors in interest of the Indiana Colony first purchased the San Pasqual rancho in 1858.

The Bradford street well, situated on a lower bench just west of Arroyo Seco, was dug and a pumping plant installed over it in 1903; the Culver well, on the east side of the arroyo, was purchased from F. J. Culver in 1904 for $8,000, and the Glenarm street wells, one-fourth mile northeast of the Raymond Hotel, were bored and equipped in the summer of 1904.

DEVILS GATE JOINT WORKS.

A brief account of these works, constructed and owned jointly by the Pasadena Land and Water Company and the Pasadena Lake Vineyard Land and Water Company, is given on pages 126–128.

INDEPENDENT PROPERTY.

The oldest of the water sources owned exclusively by the Pasadena Land and Water Company is the Sheep Corral Springs and development works. Before the sinking of wells and driving of tunnels in their immediate vicinity and the completion of more distant developments which have nevertheless affected their supply, these springs yielded from 50 to 130 miner's inches during the dry months of summer, and their average flow was given by Wm. Ham. Hall[a] as 90 miner's inches.

As the demand for water on the Pasadena mesa increased, work was undertaken at the springs, with the purpose of increasing the supply available from them. In 1890 a tunnel was begun just above the gorge at Sheep Corral Springs, at a depth of 29 feet, and during the three succeeding years it was extended northward until it reached a length of 1,345 feet, its construction having cost $14,500. At the same time (1890) a small gasoline engine was installed for the purpose of lifting the water developed in the tunnel into a receiving tank, whence it was pumped with other waters from the springs to a reservoir on the edge of the mesa 100 feet above the arroyo level. The plants for this greater lift were installed in 1882 and in 1892, and consist of two Wellington compound duplex pumps, each with a capacity of 100 miner's inches. In 1895, in order to recover whatever underflow might be escaping through the gravels of the gorge below the springs, a submerged dam was constructed across this gorge and extended from bed rock to 4 feet above the original surface of the gravels in the arroyo. The dam, which is of concrete-masonry construction, has a maximum depth of 28 feet, and a width of 4 feet and contains 336 cubic yards of material. Its cost was $5,200. Finally, in 1904 a well was sunk in the tunnel and water is now pumped from 40 feet below its floor.

[a] Irrigation in Southern California, 1888, p. 498.

The Bradford street well was dug in 1903. It is located in Pasadena, just west of Arroyo Seco and something more than 1 mile south of Sheep Corral Springs. From the bottom of the well, which is 70 feet deep, a drift extends eastward for 170 feet. The well is operated by electric power, and the water, about 8 miner's inches, is pumped directly into the South Pasadena main, which runs near by.

The Culver well, on the east side of the arroyo, about 600 feet north of the Bradford street well, was sunk in 1899 and 1900 by F. J. Culver, and was purchased by the Pasadena Land and Water Company in 1904 for $8,000. The well is 54 feet deep, and a tunnel extends northeastward 122 feet from its bottom. Water from this well is pumped into the South Pasadena main directly by electric power. The yield is approximately 40 inches for the six hours per day during which it is pumped. Neither the Bradford street nor the Culver well is used except during the dry periods of mid and late summer.

The latest addition to the Pasadena Land and Water Company plants is the Glenarm street group of three 12-inch wells, bored and equipped with a pumping plant in 1904. These wells are located about one-fourth mile northeast of the Raymond Hotel. They vary in depth from 215 to 256 feet, and their total cost was $1,840. An air lift has been installed to pump the water from the wells, and a centrifugal pump then raises it over the Orange Grove avenue ridge into the South Pasadena main. From this main the water will flow by gravity to the Sheep Corral plant, and may then be pumped into the Pasadena system. The cost of this pumping plant is given as $7,023, and its capacity as 90 inches. The wells easily yield this amount, and inasmuch as their situation is most favorable, both as to permanence of supply and accessibility of water, it is probable that they will continue to furnish the full amount for a long period.

DISTRIBUTION.

Although the San Gabriel Orange Grove Association, to whose rights and property the Pasadena Land and Water Company has succeeded, was essentially an irrigation company, the present corporation, through the growth of the cities of Pasadena and South Pasadena, has become in reality a municipal water company. Only about 100 of the 1,500 acres in the original tract are now under irrigation.

Within the city limits of Pasadena practically all services are under meter, the company having about 1,200 instruments in use. The minimum charge for water where meters are installed is $1.25 per month. This sum entitles the user to 800 cubic feet. For all water in excess of that amount a charge of 6 cents per 100 cubic feet is made. In South Pasadena and at those few points in Pasadena

where meters are not installed, flat rates of 50 cents to $2 per month are charged. The irrigating rate is 1¼ cents per hour per "surface inch," probably equivalent to a little more than 2¾ cents per hour per California miner's inch.

VALUE OF PROPERTIES.

The board of engineers, Messrs. Allin, Lippincott, and Parker, engaged in 1904 to determine the value of the property of the companies supplying Pasadena with water, summarized the value of the system, exclusive of the interest in the Devils Gate works, the Sheep Corral developments and rights, the South Pasadena portion of the system, and the real-estate holdings, as follows:

Summary of values of the property of the Pasadena Land and Water Company (west-side system) exclusive of real estate, water, and water rights.

	Cost new.	Depreciation.	Present value.
Pipe system	$78,234.52	$25,500.46	$52,734.06
Gate valves	1,655.18	297.93	1,357.25
Specials	848.12	276.49	571.63
Meters laid prior to June, 1900	8,795.10	2,506.59	6,288.51
Meters laid since June, 1900	6,557.50	565.11	5,992.39
Orange Grove avenue reservoir	26,929.67	5,088.65	21,841.02
Bradford street pumping plant	4,553.24	339.54	4,213.70
Glenarm street wells	1,840.20	.....	1,840.20
Glenarm street pumping plant	7,023.42	.....	7,023.42
Sheep Corral main pumping plant	8,480.81	3,869.33	4,611.48
Division box, three-tenths	40.50	.....	40.50
Dry tunnel, three-tenths	1,018.91	.....	1,018.91
Wagon road and fence, Devils Gate, three-tenths	194.43	9.89	184.54
Tool house and office furniture	500.00	.....	500.00
Total value of construction work, including Glenarm and Bradford street wells, and not including other development work	146,671.60	38,453.99	108,217.61
Add 20 per cent for engineering, administration, contractor's profits, etc	.....	.....	21,643.52
Value of the going business	.....	.....	10,000.00
		.....	139,861.13

The Devils Gate developments (see pp. 126–128 for details) are valued at $200,000, three-tenths of which, or $60,000, belong to the west-side system. The water supply from Sheep Corral Springs was valued at $500 per miner's inch, and the permanent supply there estimated at 50 miner's inches, or a total valuation of $25,000. T. D. Allin, city engineer of Pasadena, estimated that portion of the company's plant outside of the city to be worth $15,295.73, and the real estate commission estimated the value of the real estate holdings of the corporation to be $49,603.28.

The final valuation of the west-side company's property may therefore be summarized thus:

Value of property of Pasadena Land and Water Company.

Plant in Pasadena (exclusive of Devils Gate and Sheep Corral developments)	$139,861.13
Three-tenths interest in Devils Gate developments	60,000.00
Sheep Corral developments and supply	25,000.00
Real estate	49,603.28
Portion of plant outside of Pasadena	15,295.73
	289,760.14

VERDUGO CANYON WATER COMPANY.

The waters of Verdugo Canyon are percolating waters of rather uniform flow, which escape from gravels that fill the valley of La Cañada, between the San Rafael and Verdugo hills to the south and the San Gabriel Range to the north. They drain into the lower San Fernando Valley through Verdugo Canyon, rising to the surface in a number of springs along the southern 1¾ miles of its course. The flow from these springs forms two small surface streams, one on either side of the canyon. By a court decree, handed down in November, 1871, the waters on the east side of the canyon were awarded to Theodore Verdugo and his assigns, and made appurtenant to 2,629.01 acres lying within the limits of the canyon. Since the award, portions of the tract have been sold, and there are now several owners of the east-side water. By the same decree all surplus east-side water, above that reasonably required by Verdugo and his successors in interest, was to be turned into the channel of the west-side springs and to become a part of those waters which were allotted to lands lying in the east end of the San Fernando Valley below the canyon. This west-side water was divided into 10,000 parts, and apportioned among the various interests claiming it. The division was made by time, an owner of one part being entitled to the total west-side flow for one minute of each week.

June 18, 1884, the Verdugo Canyon Water Company was organized to better effect the distribution of this west-side water by constructing and maintaining a system of pipe lines, hiring a zanjero, etc., and to develop the underflow of the canyon. The capital stock was fixed at $10,000, divided into 10,000 shares, each representing one of the original 10,000 parts of the west-side water. Three-fourths of the owners of the west-side interests joined the organization, and 7,500 shares were issued, C. E. Thom and E. M. Ross, owners of one-fourth interest, remaining outside the company. No subscriber to the capital stock of the company may hold more shares than he owns ten-thousandths of west-side water. There are 300 stockholders, each of whom receives a proportion of the total flow equal to the ratio of his stock to the total issue of 10,000 shares. Only six of these stockholders, however, receive their water directly from the company's pipe lines. The remainder have organized a number of subordinate

companies. These companies and the number of ten-thousandths of west-side water which they receive are listed in the following table:

Subordinate companies receiving west-side water of Verdugo Canyon.

Verdugo Springs Water Company	666
Verdugo Pipe and Reservoir Company	1,307.5
Tropico Water Company	1,191
Independent Water Company	924.5
North Glendale Pipe and Reservoir Company	2,128
East Glendale Reservoir and Pipe Company	670
Glassell Pipe Company	613

Five of these subsidiary companies own reservoirs, and the share of each is delivered to it in a constant flow. The West Glendale Reservoir and Pipe Company and the Glassell interests do not own reservoirs, and their share of water is delivered once or twice weekly in accumulated heads. The Verdugo Canyon Water Company also delivers to C. E. Thom and E. M. Ross their proportion of canyon water, collecting from them a proportionate share of operating expenses.

The responsibility of the Verdugo Canyon Water Company ceases with the delivery of its share of water to each of the subordinate companies. The further subdivision of the water and its delivery to the individual stockholders, through the pipe lines and reservoirs of the subordinate companies, is charged for by the companies.

During the five seasons covering the years 1900 to 1904 the average annual expenses of the Verdugo Canyon Water Company were 27 cents per share. This charge covered operation, maintenance, legal fees, and other expenses, and a payment of $2,500 on the indebtedness. The total flow, surface and developed, controlled by the company varies from 65 to more than 100 inches. The maximum surface flow recorded, 171 miner's inches, was measured in August, 1890. The minimum combined surface and developed underflow, 64.2 miner's inches, was measured October 1, 1904. Other records of measurements are given below:

Measurements of Verdugo Canyon waters.

Date.	Surface flow.	Underflow diverted by dam.	Total.
	Miner's in.	*Miner's in.*	*Miner's in.*
May 14, 1904	51	26.7	77.7
August 14, 1904	45.6	19.7	65.3
May 27, 1905	77.7	23.9	101.6

Soon after the incorporation of the Verdugo Canyon Water Company, steps were taken to divert the canyon water. A masonry dam 50 feet long was built across the bed of the creek, a short distance below the tract now known as Verdugo Park. No attempt was made

to reach bed rock, the base of the dam being sunk only 6 feet below the surface. From the dam about 26,000 feet of 16-, 10-, and 8-inch cement pipe were laid to the reservoirs below. Practically this same system remains in existence to-day, the only change being an extension of 500 feet of 25-inch cement main upstream to the submerged dam begun in 1895. Preparations for this latter construction had been made in 1894 by the purchase of $7\frac{4}{5}$ acres of land, above the old diversion dam, for $2,500, all of the west-side interests joining in the purchase. Explorations for bed rock were carried out, and as they resulted favorably, construction was about to be undertaken when it was found impossible to procure a direct right of way across the canyon from the owner of the adjoining property on the east. An alternative indirect right of way was offered, however, and accepted, and construction was begun. Two hundred and forty feet of dam had been built when the channel deepened and bed rock was lost. Exploration for it resulted in an estimate that the dam could not be completed for less than $50,000. As $20,000 had already been expended, the estimate was considered prohibitive and work was stopped. This incomplete dam results in the recovery of some of the underflow, as is indicated by the table on page 136.

YIELD OF FLOWING WELLS.

In the endeavor to use tables heretofore published, for the easy determination of the yield of flowing wells when the diameter of the casing and the height of the dome are known, difficulties have been encountered, the majority of the tables extant proving inaccurate. The most satisfactory formulas known to the writer for the yield of wells discharging vertically are those of C. E. Grunsky. From these formulas, which are given below, a set of simple tables of the yield of wells flowing 250 California miner's inches or less has been compiled. These tables have proved convenient in the field work of the author of this report, and it is hoped that they may prove equally useful to others.

Grunsky's formulas for yield of flowing wells.

[Q=Gallons per minute; d=diameter; h=dome.]

When $h>d$ (spouting wells), $Q=5.35d^2\sqrt{h}$

When $h<\frac{1}{10}d$, $Q=10d\sqrt{h^3}$

When $h<d$ and $>\frac{1}{10}d$, $Q=\dfrac{10dh\sqrt{h}}{\sqrt{1+2.525\left(\frac{h}{d}\right)^2}}$

Yield of flowing wells.

[California miner's inch of 9 gallons per minute or 0.02 second foot.]

Height of dome, in inches. \ Diameter of well, in inches.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0.2	½	½	½	½	½	½	1	1	1	1	1	1	1	1	1
.4	½	1	1	1	1	2	2	2	3	3	3	3	4	4	4
.6	½	1	2	2	2	3	3	4	4	5	5	6	6	7	7
.8	1	1	2	3	4	4	5	6	7	8	8	9	10	10	11
1.0	1	2	3	4	5	6	7	8	9	11	12	13	14	15	16
1.2	1	2	4	5	7	8	9	11	13	14	16	17	19	20	21
1.4	1	2	4	6	8	10	12	14	16	18	20	22	24	25	27
1.6	1	3	5	7	10	12	15	17	19	21	24	26	29	31	34
1.8	1	3	5	8	12	14	17	20	23	25	28	31	34	36	40
2.0	1	3	6	9	13	16	19	23	26	29	32	36	40	42	46
2.2	1	3	6	11	15	18	22	26	30	34	37	41	45	49	52
2.4	1	4	7	12	16	20	25	30	34	38	42	46	50	55	59
2.6	1	4	7	13	18	22	28	32	38	42	47	51	37	61	67
2.8	1	4	8	14	19	24	31	36	42	47	52	57	63	69	75
3.0	1	4	9	15	21	26	33	40	46	51	57	63	70	76	83
3.2	1	4	10	16	22	28	35	43	50	56	62	70	77	83	90
3.4	1	4	10	17	23	30	38	46	53	60	68	77	84	91	99
3.6	1	4	11	17	24	32	41	49	57	65	73	82	91	99	107
3.8	1	4	11	18	26	34	43	52	61	70	80	89	97	106	115
4.0	1	5	11	18	27	36	46	56	65	75	85	94	103	113	123
4.2	1	5	11	19	28	38	48	58	69	80	90	100	110	121	132
4.4	1	5	12	19	29	39	50	61	73	85	96	106	117	129	141
4.6	1	5	12	20	30	41	52	64	77	90	101	112	124	138	149
4.8	1	5	12	20	31	42	54	67	81	94	106	118	131	145	156
5.0	1	5	12	21	32	44	57	70	84	97	111	124	139	153	164
5.2	1	5	12	21	33	45	59	73	87	101	116	130	146	160	172
5.4	2	5	12	22	34	46	61	76	91	106	121	136	152	168	178
5.6	2	5	13	22	34	48	62	79	94	110	126	142	157	175	188
5.8	2	5	13	23	35	49	65	81	97	114	131	148	164	181	198
6.0	2	5	13	23	36	50	67	84	100	118	136	154	172	187	206
6.2	2	5	13	24	36	51	68	86	104	121	141	159	177	196	213
6.4	2	6	14	24	37	52	70	89	107	126	146	164	185	204	222
6.6	2	6	14	24	38	53	72	91	111	130	151	170	190	210	230
6.8	2	6	14	25	39	54	73	93	114	134	155	175	197	218	237
7.0	2	6	14	25	39	56	75	96	116	138	160	181	204	225	246
7.2	2	6	14	25	40	57	76	98	119	142	164	187	210	232	....
7.4	2	6	14	26	40	58	78	100	122	146	168	193	215	240	....
7.6	2	6	15	26	41	58	79	102	124	149	173	199	221	247	....
7.8	2	6	15	26	41	59	80	104	128	152	177	204	227	....	....
8.0	2	6	15	27	42	60	81	106	130	154	182	208	233	....	....
8.2	2	6	15	27	42	60	82	108	133	157	187	212	240	....	....
8.4	2	7	15	27	43	61	83	110	136	160	191	217	247	....	....
8.6	2	7	15	28	43	62	85	111	138	163	196	221	....	....	....
8.8	2	7	15	28	44	63	86	113	140	167	200	225	....	....	....
9.0	2	7	16	28	44	63	87	114	142	170	204	229	....	....	....
9.2	2	7	16	29	45	64	88	116	144	175	207	235	....	....	....
9.4	2	7	16	29	45	65	89	117	146	178	210	241	....	....	....
9.6	2	7	16	29	46	66	90	118	148	180	213	246	....	....	....
9.8	2	7	16	30	47	67	91	119	150	184	217	251	....	....	....
10.0	2	7	17	30	47	68	92	121	153	187	220	....	....	....	....

MAPS AND TABLES.

Such information on the foothill belt as is capable of graphic presentation has been assembled in maps and tables.

The maps (Pls. III–IX, in pocket) show the lands irrigated in the foothill belt, the chief pipe and canal lines of the various irrigating companies, the pumping plants, the artesian wells, a few of the domestic wells, ground-water levels, indicated by hydrographic contours, and artesian areas past and present.

In the tables the information collected during a careful canvass of the wells of the foothill belt has been assembled. This information includes the name of the owner, the location of the well, the date of its completion, its diameter, depth, and cost, the cost of the installation where pumping machinery is in use, the use made of the water, and the amount produced. For some wells temperature data and rough determinations of the amount of solid matter in the

water in parts per 100,000, as a result of measurements of the electric resistance by the Wheatstone bridge, are included.

It has not been possible to obtain all of this information for each well examined, and in many cases that collected is only approximately correct, but such facts as are known are presented.

The greater part of the data thus assembled, both in the tables and maps, has been collected by W. N. White, field assistant, to whom cordial acknowledgments are due. In assembling the material in the office for publication, both Mr. White and A. J. Fisk, jr., have assisted.

The following list of useful equivalents has been compiled by J. B. Lippincott:

USEFUL EQUIVALENTS.

1 United States gallon of water weighs 8.345 pounds.
1,000,000 gallons per day=1.54723 second-feet.
1 cent per 1,000 gallons=$3.367 per acre-foot.
1 old California miner's inch=1,728 cubic feet per day, or
$\frac{1}{50}$ second-foot, or
12,925 gallons per day, or
538.5 gallons per hour, or
630,720 cubic feet per year, or
14,478 acre-feet per year.
1 new California miner's inch=$1\frac{1}{2}$ cubic feet per minute, or
$\frac{1}{40}$ second-foot.
1 Colorado miner's inch=2,250 cubic feet per day, or
17,000 gallons per day (approximately).
1 second-foot=50 California miner's inches, or
38.4 Colorado miner's inches, or
450 gallons per minute, or
723.92 acre-feet per year, or
1.983471 acre-feet in 24 hours, or
$59\frac{1}{2}$ acre-feet in 30 days, or
646,315 gallons per day.
1 second-foot per year=13.57 inches in depth per square mile.
1 acre-foot=25.2 California miner's inches for 24 hours, or
43,560 cubic feet, or
325,851 United States gallons.
2 acre-feet in 30 days=continuous flow of $0.03\frac{1}{3}$ second-foot.
1 cubic foot=7.4805 gallons.
1 cubic foot of water at 62° F. weighs 62.355 pounds.
1,000,000 cubic feet=23 acre-feet (approximately).
1 barrel crude oil=42 gallons.
1 barrel crude oil of 14° gravity weighs 340.6 pounds (usually taken at 341 pounds).
1 gallon crude oil weighs 8.12 pounds.
Pressure per square inch for each foot of head=0.433 pound.
Pressure in pounds per square inch × 2.31=head in feet.
Grains per gallon × 1.71=parts per 100,000 of solids.
Velocity of 1 mile per year=0.000167 foot per second.

GENERAL STATISTICS.

Flowing wells, pumping plants, irrigated area, etc., in foothill belt of southern California in 1905.

	Cucamonga quadrangle.	Pomona quadrangle.	Pasadena quadrangle.	Total.
Number of flowing wells	25	0	13	38
Number of pumping plants	107	93	168	368
Estimated investment in wells and pumping equipment	$388,839	$355,643	$448,642	$1,193,124
Estimated average output, continuous flow, second-feet	25	20	40	85
Area irrigated ... acres	21,643	17,288	16,750	55,681
Artesian area, 1905 ... square miles	3.5	0	1.3	4.8
Original artesian area ... do	4.75	1.1	2	7.6
Estimated area tillable land ... do	150	147	148	445

WELL DATA.

Wells in the foothill belt of southern California.

CUCAMONGA QUADRANGLE.

[*Cost of well and equipment combined; † yield estimated or statement of owner taken; ? doubtful. The miner's inch used in these tables is the old California miner's inch, i. e., the amount of water which flows from a 1-inch orifice under a 4-inch head; it is equal to 9 gallons per minute, 14.478 acre-feet per year, or one-fiftieth second-foot.]

No. of well.	Owner.	Location.	Map location.	Year completed.	Class of well.	Elevation of surface (feet)—approximate only.	Elevation of water (feet).	Depth of well (feet).	Solids per 100,000.	Temperature of water (°F.).	Method of lift.	Cost of well.	Cost of machinery.	Use of water.	Quantity of water (inches).
1	D. G. Henderson	Sec. 16, T. 1 N., R. 6 W	N-6	1883		2,300					Tunnel			Irrigation	† 5
2	Sexton Bros.	Sec. 5, T. 1 S., R. 6 W.	M-10	1901	Bored, 10-inch	1,280	980	1,000?				$4,000.00?		Not used	
3	Joseph Geeman	Sec. 20, T. 1 S., R. 6 W.	M-12, 13	1886	Bored, 2-inch	1,040	810	300			Wind	300.00	$80.00	Domestic	
4	H. Schoenfelder	Sec. 33, T. 1 S., R. 6 W.	N-14	1896	Dug, 3½ by 2½ foot.	910	768	160			do	250.00	90.00	do	
5	Riverside Vineyard Co.	Sec. 4, T. 2 S., R. 6 W.	M-15	1900	Bored, 12-inch	840	740	400			Steam	500.00	7,500.00	Irrigation	† 175
6	H. Maittral	Sec. 32, T. 1 S., R. 6 W.	M-15	1896	Bored, 7-inch	850	698	230			Wind			Domestic; stock	
7	Riverside Vineyard Co.	Sec. 4, T. 2 S., R. 6 W.	M-16	1889	Bored, 10-inch	805	685	176			do	250.00	100.00	do	
8	do	do	M-16	1895	Bored, 8-inch	798	684	150			do	200.00	75.00	Stock	
9	Union school district.	do	M-16	1894	Bored, 7-inch	785	700	145			do	250.00	75.00	Domestic	
10	I. N. Van Nuys	Sec. 10, T. 2 S., R. 6 W.	M-17	1884	do	740	650	150			do	300.00	75.00	Domestic; stock	
11	do	do	N-16, 17	1884	do	775	687	143			Not raised	275.00	75.00	Not used	
12	G. M. Laren	Sec. 8, T. 2 S., R. 6 W.	M-17	1894	do	770	686	148			Wind			Domestic	
13	R. L. Summerwell	do	L-16	1895	do	780	687	140			do	200.00	100.00	Not used	
14	F. A. Gallwas	Sec. 6, T. 2 S., R. 6 W.	K-16	1892	do	790	671	154			do	200.00	100.00	Domestic; stock	
15	C. Carroll	Sec. 7, T. 2 S., R. 6 W.	L-16	1890	do	770	686	100			Not raised			Not used	
16	A. T. Galloway	Sec. 6, T. 2 S., R. 6 W.	L-16	1896	do	790	689	139			Wind	225.00	75.00	Domestic	
17	R. T. Garner	do	L-15	1885	do	840	703	164			Hand	300.00		do	
18	A. T. Galloway	do	L-16	1895	do	825	687	140						Not used	

19	Mrs. M. L. Johnson	do	K-15	1892	do	840	703	164			Wind	225.00	100.00	Domestic; stock	
20	A. La Fourcade	Sec. 29, T. 1 S., R. 6 W.	L-14	1889	Bored, 8-inch	965	645	400			do	700.00	100.00	do	
21	Smith Bros	Sec. 7, T. 1 S., R. 6 W.	L-11	1903	Dug, 4½ by 4½ foot, 158 feet; bored, 12-inch, 492 feet.	1,125	895	650	23		Steam	3,000.00		Irrigation	†15
22	Cucamonga winery	Sec. 11, T. 1 S., R. 7 W.	J-11	1903	Bored, 5-inch	1,122	822	497	21		Gas	2,500.00	3,000.00	Winery	†3
22a	do	do	J-11	1903	Bored, 12-inch	1,122	805	540	21		do	3,000.00		do	†5
23	Colonel Post	Sec. 18, T. 1 S., R. 7 W.	K-11		Bored, 7-inch	1,110	820	420						Not used	
24	Benton Ballou	Sec. 26, T. 1 S., R. 7 W.	J-14	1892	do	885	756	158	23		Wind	250.00	100.00	Domestic; stock	
25	Mrs. Martha Collins	Sec. 35, T. 1 S., R. 7 W.	J-14	1884	do	865	705	180	23		do	300.00	100.00	do	
26	A. T. Hamilton	do	J-14	1888	do	880	702	252			do	640.00	150.00	do	
27	Thos. Monks	do	J-15	1900	do	845	717	164	22		do	250.00	100.00	do	
28	J. R. Merrill	Sec. 2, T. 2 S., R. 7 W.	J-16	1901	do	830	711	151	21		do	250.00	75.00	do	
29	F. H. Hollister	Sec. 11, T. 2 S., R. 7 W.	J-16	1892	do	785	673	148	22		Hand	180.00	38.00	Not used	
30	L. H. Farron	do	J-16		do	785	676	125	22					do	
31	R. W. Henderson	Sec. 12, T. 2 S., R. 7 W.	J-16	1892	do	790	695	117	23		Wind	225.00	125.00	Domestic; stock	
32	Wm. B. Jackson	Sec. 11, T. 2 S., R. 7 W.	J-17	1901	do	740	663	113	23		do	152.00	125.00	do	
33	D. McDougall estate.	Sec. 14, T. 2 S., R. 7 W.	I-17	1896	do	730	678	81				75.00	75.00	Not used	
34	L. Bergstrom	Sec. 10, T. 2 S., R. 7 W.	I-17	1896	do	735	680	79			Wind	100.00	90.00	do	
35	J. Martinas	do	I-17	1896		740	688	100							
36	A. H. Blakeley	do	I-17	1892	Bored, 7-inch	755	695	75	22		Wind	100.00	85.00	Domestic; stock	
37	George W. Ingram	do	I-17	1892	do	750	689	100	22		do	175.00	150.00	Domestic	
38	Charles Lambe	do	I-17	1896	do	735	677	112	22		do	95.00	125.00	Domestic; stock	
39	Torence Pratt	do	I-17	1896	do	745	684	86			do			Not used	
40	William Riggs	Sec. 11, T. 2 S., R. 7 W.	I-17	1889	do	760	681	99			Not raised			do	
41	Arthur Pooley	Sec. 10, T. 2 S., R. 7 W.	I-17	1897	do	765	690	88	20		Wind	100.00	100.00	Domestic	
42	Mr. Searls	do	I-16	1893	do	775	Dry.	61							
43	Mountain View district school.	Sec. 2, T. 2 S., R. 7 W.	I-16	1887	do	810	700	140	21		Wind	250.00	175.00	Domestic	
44	D. F. Stoner	Sec. 3, T. 2 S., R. 7 W.	I-16	1894	do	825	710	165	21		do			do	
45	George Andrews	Sec. 33, T. 1 S., R. 7 W.	H-14		do	890	760	138			do			Not used	
46	Mr. Eason	do	H-14		do	880	756	130						do	
47	do	Sec. 28, T. 1 S., R. 7 W.	H-14	1961	Bored, 10-inch	930	Dry.	173						do	
48	James Quibell	Sec. 27, T. 1 S., R. 7 W.	I-14	1902	do	915	770	211			Gas	371.00	1,350.00	Irrigation	†15

Wells in the foothill belt of southern California—Continued.

CUCAMONGA QUADRANGLE—Continued.

No. of well.	Owner.	Location.	Map location.	Year completed.	Class of well.	Elevation of surface (feet)—approximate only.	Elevation of water (feet).	Depth of well (feet).	Solids per 100,000.	Temperature of water (°F.).	Method of lift.	Cost of well.	Cost of machinery.	Use of water.	Quantity of water (miner's inches).
49	Mr. Southworth	Sec. 32, T. 1 N., R. 6 W.	L-9			1,325	Dry.	320							
50	J. Bennett	Sec. 1, T. 1 S., R. 7 W.	K-10			1,210	Dry.	200							
51	O. Bartell	Sec. 8, T. 1 S., R. 6 W.	M-10		Dug, 4 by 4 foot.	1,210	Dry.	200							
52	Mrs. Louis Smith	Cucamonga	I-11	1899	Dug, 3 by 3 foot.	1,175	Dry.	149				$200.00			
53	Old Settlers Water Co.	do	I-10	1902	Bored, 15-inch, 180 feet; 12-inch 120 feet; 10-inch, 48 feet.	1,315	1,271	348	23		Gas	1,047.00	$1,900.00	Irrigation	†32
54	Sunset Water Co.	do	I-9	1901	Dug, 5 by 7 foot, 110 feet; bored, 15-inch, 200 feet; 12-inch, 555 feet.	1,395	1,305	865			Electric motor	4,000.00	2,500.00	do	†30
55	do	do	I-9	1900	Dug, 4 by 6 foot; bored, 12-inch.	1,410	1,324	190						Not used	
56	Hermosa Water Co.	do	I-8	1901	Bored, 10-inch	1,520	1,360	275			Gas	800.00	2,500.00	Irrigation	†30
58	Upland Water Co.	do	H-9	1901	Dug, 5 by 7 foot, 110 feet; 7 by 14 foot, 63 feet; bored, 12-inch, 261 feet.	1,560	1,387	434			Steam		3,400.00	do	†40
59	Cucamonga Water Co.	do	H-9	1897	Bored, 12-inch, 381 feet; 8-inch, 160 feet.	1,429	1,343	541	20	71		1,500.00		Not used	
60	do	do	H-9	1897	Dug, 4 by 6 foot, 114 feet; bored, 12-inch, 195 feet; 8-inch, 195 feet.	1,457	1,355	479	21	72	Electric motor			Irrigation	†25

61	do	do	I-9	1899	Bored, 9½-inch	1,358	1,271	456	17	72	Flows into tunnel.			do	5
62	do	do	I-10	1899	Dug, 40 feet; bored, 9½-inch, 464 feet.	1,346	1,265	504			Electric motor			do	†50
63	do	do	I-9	1899	Dug, 47 feet; bored, 9½-inch, 386 feet.	1,389	1,292	433	17	72	Flows into tunnel.			do	†3
64	do	do	I-10	1899	Dug, 90 feet; bored, 9½-inch, 338 feet.	1,395	1,298	428		73	do			do	†4
65	do	do	I-9	1899	Bored, 9½-inch	1,376	1,276	547			do			do	†2
66	do	do	I-9	1899	do	1,379	1,283	287			do			do	†4
68	do	do	G-10	1897	do	1,388	1,303	371						Not used	
69	do	do	G-10	1899	Bored, 12-inch, 366 feet; 10-inch, 300 feet.	1,374	1,294	666		64	Flows into tunnel.			Irrigation	
70	do	do	G-10	1904	Bored, 10-inch	1,395	1,299	540			do			do	†35
71	do	do	G-10	1901	Bored, 15-inch, 224 feet; 12-inch, 296 feet.	1,398	1,300	520			do			do	†40
72	do	do	G-10											Not used	
73	San Antonio Water Co.	do	G-9	1901	Dug, 5 by 8 foot, 110 feet; bored, 12-inch, 528 feet.	1,488	1,365	638		62	Electric motor			Domestic; irrigation.	†75
74	do	do	G-9	1901	Dug, 125 feet; bored, 12-inch, 499 feet.	1,483	1,351	624	20	62	do			Irrigation	†75
75	do	do	G-9	1898	Dug, 124 feet; bored, 12-inch, 516 feet.	1,482	1,352	640	19	62	do			do	†75
76	do	do	G, H-9	1901	Dug, 126 feet; bored, 10-inch 414 feet.	1,493	1,361	540	20	62	do			Domestic; irrigation.	†75
77	do	do	H-9	1901	Dug, 130 feet; bored, 7-inch, 270 feet.	1,495	1,365	400			do			Irrigation	†75
78	do	do	H-9		Dug, 103 feet; bored, 9½-inch.	1,480	1,364		21	60	do			do	†30
79	do	do	H-9	1900	Dug, 142 feet; bored, 12-inch, 507 feet (2 wells).	1,495	1,356	649		70	do			do	†150
80	do	do	G-10	1902	Bored, 15-inch	1,410	1,310			64	do			do	†175
85	Stewart & Co	do	E-8	1898	Dug, 3 by 5 foot	1,805	Dry.	250							
86	Canyon Ridge Water Co.	do	E-8	1898	Dug, 4 by 5 foot	1,815	1,700	165			Gas			Irrigation	†25
87	S. A. Bard	do	E-8	1896	Dug, 3 by 6 foot	1,820	1,710	160	23		do		1,200.00	do	†20
88	San Antonio Water Co.	do	E-8	1903	Dug, 5 by 12 foot, 182 feet; bored, 14-inch, 228 feet.	1,820	1,710	410				2,000.00		do	

Wells in the foothill belt of southern California—Continued.

CUCAMONGA QUADRANGLE—Continued.

No. of well.	Owner.	Location.	Map location.	Year completed.	Class of well.	Elevation of surface (feet)—approximate only.	Elevation of water (feet).	Depth of well (feet).	Solids per 100,000.	Temperature of water (°F.).	Method of lift.	Cost of well.	Cost of machinery.	Use of water.	Quantity of water (miner's inches).
89	San Antonio Water Co.	Cucamonga	E-9		Dug	1,875	1,705	212						Not used	
90	Colonel Paul and C. D. Adams.	do	E-8	1897	Dug, 4 by 5 foot.	1,885	1,700	220			Electric motor.			Irrigation	† 16
92	James Illingworth	do	E-7	1901	Dug, 3 by 5 foot.	2,160	2,026	143		61	Wind	$400.00	$125.00	Domestic irrigation.	
94	San Antonio Water Co.	Sec. 25, T. 1 N., R. 8 W.	E-9	1895	Dug, 4 by 4 foot.	1,718	Dry.	100				500.00		No water	
97	do	do	E-8, 9	1895	do	1,745	Dry.	122				600.00		do	
98	do	do	E-9	1895		1,695	Dry.	102						do	
99	Citizens' Bank of Ontario.	Cucamonga	F-9	1898	Dug, 5 by 5 foot.	1,535	Dry.	275							
101	William Littlewood.	do	E-9	1899	Dug, 4 by 5 foot.	1,590	Dry.	300				700.00			
102	J. W. Mabb	do	F-9		Dug, 3 by 4½ foot.	1,525	Dry.	128							
103	Kirk Farlow Water Co.	do	F-8, 9		Dug, 3 by 5 foot.	1,645	Dry.	204							
104	Doctor Fargo	do	F-7		Dug, 4 by 6 foot.	1,925	Dry.	400							
105	San Antonio Water Co.	do	G-7	1896	Dug						Tunnel	80,000.00?		Irrigation	† 10
108	Mr. Hemen	Sec. 27, T. 1 N., R. 8 W.	C-8	1896	do	1,735	1,697	40			Wind			Stock	
109	Mountain View Water Co.	Sec. 2, T. 1 N., R. 8 W.	D-10	1899	Dug, 5 by 6 foot, 63 feet; bored, 10-inch, 62 feet.	1,412	1,354	125			Gas	750.00	475.00	Irrigation	† 15
110	do	do	D-10	1899	Dug, 5 by 6 foot, 93 feet; bored, 10-inch, 47 feet.	1,410	1,354	140			do	1,000.00	750.00	do	† 30
111	do	do	C-10	1892	Dug, 4 by 5 foot, 71 feet; bored, 8-inch, 42 feet.	1,390	1,352	113		62	Flows into tunnel.			do	
112	B. K. Brant	Sec. 12, T. 1 N., R. 8 W.	D-10	1900	Dug, 4 by 6 foot.	1,350	Dry.	507				2,000.00		do	
113	J. L. Means	Sec. 15, T. 1 S., R. 8 W.	C-12	1900	Bored, 10-inch	1,050	783?	331			Gas	900.00	2,000.00	do	† 30
113a	do	do	C-12	1901	Bored, 14-inch	1,050	782?	350			do	1,000.00			

114	M. W. Cobban	Sec. 22, T. 1 S., R. 8 W.	C-13	1899	Bored, 7-inch	1,005	800	260	20		Wind	700.00	175.00	Domestic	
115	W. L. Holmes	do	C-13	1903	Bored, 10-inch	965	777	280	19	64		640.00		Not installed	
116	F. E. Jones	Sec. 26, T. 1 S., R. 8 W.	C-14	1902	Bored, 7-inch	945	773	408			Wind	700.00	350.00	Domestic; irrigation.	
117	Mr. McLaughlin	Sec. 23, T. 1 S., R. 8 W.	D-13		do	980	775	208			do			Not used	
118	Mrs. M. H. Fitch	do	D-13		do	995	785	250	22	58	do				
119	Fortier, Green & Hill Water Co.	do	D-13	1899	Bored, 10-inch	1,015	783	334	21	59	Gas	800.00	1,700.00	Irrigation	† 20
120	J. Sternberg	do	D-13	1898	do	990	780	308	21	62	do	800.00	1,500.00	Domestic; irrigation	† 10
121	Crawford Bros	Sec. 26, T. 1 S., R. 8 W.	D-13	1899	Bored, 10½-inch (2 wells).	980	775	325	20		do	800.00	5,000.00	Irrigation	† 35
122	J. Sullivan	Sec. 25, T. 1 S., R. 8 W.	E-13	1903	Bored, 9½-inch	990	770	335	19		Electric motor	815.00		do	† 20
123	A. L. King	do	E-13	1899	Bored, 12-inch	995	771	476	21		Gas	1,000.00	1,700.00	do	† 17
124	Lyman Stewart	Sec. 24, T. 1 S., R. 8 W.	E-12	1901	Dug, 6 by 8 foot, 320 feet; bored, 12-inch, 180 feet.	1,085	780	500			Steam	5,000.00	5,000.00	do	† 20
125	George Hocknell	do	E-13	1900	Bored, 10-inch	1,043	767	320			Not raised	850.00		Not used	
126	George C. Hagar	Sec. 21, T. 1 S., R. 7 W.	H-13	1895	Dug, 4 by 4 foot, 176 feet; bored, 7-inch, 44 feet.	980	782	220			do			do	
127	R. H. Hannah	Santa Ana del Chino.	F-14	1900	Bored, 10-inch	931	758	211			Wind	350.00	125.00	Domestic; irrigation.	
128	James H. Sauerwein	Sec. 1, T. 1 S., R. 8 W.	E-9	1894	Dug, 3 by 5 foot	1,540	Dry.	300				2,000.00		No water	
129	Doctor Turner	Santa Ana del Chino.	D-15		Bored, 10-inch (2 wells).	865	750	125	27		Wind			Irrigation	
130	Edward Chapman	do	D-16		Bored, 7-inch	810	746	150	27		do			Domestic; stock	
131	F. E. Schaad	do	D-16	1894	do	785	739	375	30	64	Gas			Irrigation	
132	H. C. Roberts	do	D-16	1899	do	775	739	126	19	67	do	500.00	300.00	Domestic	
133	Stephen Bush	do	D-16	1894	do	770	728	53			Wind		75.00	do	
134	J. B. Mart	do	D-16	1900	do	765	729	160	20	64	do			do	
135	C. W. Brenell	do	D-17	1903	do	740	717	112			do	100.00	75.00	do	
136	H. E. Benjaman	do	D-17	1901	do	725	700	160		68	do	200.00	100.00	do	
137	Mrs. E. G. Tateng	do	D-17	1897	Dug, 4 by 4 foot	705	682	25	21		do			do	
138	C. Nabakowski	do	E-17	1900	Bored, 7-inch	705	701	255						Not used	
139	American Beet and Sugar Co.	do	E-17			695	695	300		69	Artesian			do	
140	J. T. Curlee	do	E-17	1900	Driven, 2-inch	715	704	13	19	68	Hand			Domestic	
141	W. C. Rightmier	do	E-17	1894	Bored, 7-inch	690	690	148	19	67	Gas, artesian	240.00	415.75	Irrigation	a† 22
142	W. J. Schaefer	do	E-17	1897	do	695	695	323			do	700.00	700.75	Domestic; irrigation.	b† 4
143	L. Anderson	do	D-17	1900	do	690	690	243			Artesian			Irrigation	4
144	W. C. Rightmier	do	D-17	1901	do	680	680	126			do			do	5
145	Mr. Dunn	do	D-17		do	675			19	67	do			Domestic; stock	
146	Z. Wilkison	do	D-16		Dug, 3½ by 3½ foot.	760	721	41	22		Hand			Domestic	

a Pumped.

b Flow.

Wells in the foothill belt of southern California—Continued.

CUCAMONGA QUADRANGLE—Continued.

No. of well.	Owner.	Location.	Map location.	Year completed.	Class of well.	Elevation of surface (feet) approximate only.	Elevation of water (feet).	Depth of well (feet).	Solids per 100,000.	Temperature of water (° F.).	Method of lift.	Cost of well.	Cost of machinery.	Use of water.	Quantity of water (gallons).
147	F. M. Hildebrand	Santa Ana del Chino.	D-16	1903	Bored, 7-inch	745	721	138	23		Gas, wind	$100.00	$230.00	Domestic; irrigation.	
148	State Experiment Station.	do	C-15, 14	1899	do	855	761	142	23		Wind			Domestic; stock.	
149	W. McCain	do	C-15	1895	do	825	733	162+			do			Domestic; irrigation.	
150	A. Armstrong	do	C-15	1900	Bored, 10-inch	830	740	412			Gas		2,000.00	do	† 70
151	J. M. Mitchell	do	C, D-15	1900	Bored, 12-inch	860	750	336			do	800.00	1,975.00	Irrigation	† 30
152	Mrs. L. D. Greene	do	C-17	1896	Bored, 7-inch	720	709	135			Wind			Domestic	
153	Victor Gustafson	do	C-16	1902	Bored, 10-inch	735	719	640			Gas	1,500.00	1,000.00	Irrigation	† 60
154	O. W. Lorbeer	do	C-16	1888	do	755	727	973						Not used	
155	George E. Hollister	do	C-16	1903	Bored, 7½-inch	756	723	180	19		Wind	250.00	85.00	Domestic; irrigation.	
156	Black Bros. & Woodhead.	do	C-16	1903	Bored, 10-inch	743	725	718			Gas	1,000.00	1,000.00	Irrigation	† 80
157	Mrs. E. M. Day	do	C-16	1899	Bored, 7-inch	725	716	314				500.00		Not installed	
158	I. Bristol	do	B-16	1891	Bored, 4-inch	720	717	150			Wind	225.00	75.00	Domestic	
159	Mrs. M. A. Murdock	do	B-16	1899	Bored, 7-inch	715	715	247			Gas	500.00	800.00	Irrigation	
160	F. E. Reimers	do	B-16	1902	do	780	734	65			Wind	85.00	75.00	Domestic	
161	M. Payne	do	B-15	1892	do	780	734	50			do	62.50	90.00	do	
162	W. E. Jones	do	B-15	1892	Bored	785	742	900			Gas			Irrigation	† 35
163	John O'Donnell	do	B-15	1899	Bored, 10-inch	810	755	374	20	66	do		2,000.00	do	† 80
164	do	do	B-15	1889	do	795	742	160			Wind			Domestic; stock.	
165	American Beet and Sugar Co.	do	D-17		Bored, 9-inch	700	694	319			Compressed air.			Factory	
165a	do	do	D-17		do	700	694	138			do			do	
166	do	do	D-17		Bored	695	695?	309			do			do	
166a	do	do	D-17		do	695	695?	297			do			do	
167	do	do	D-17		do	690	690	481			Compressed air, artesian.			do	
168	do	do	D-17		Bored, 8-inch	700	696?	250			Compressed air.			do	
168a	do	do	D-17		Bored, 7-inch	700	696?	223			do			do	
169	do	do	D-17	1897	Bored, 8-inch	690	690?	315			do			do	
169a	do	do	D-17	1897	Bored	690	690	250			do			do	
170	do	do	B-16		Bored (5 wells)	735	729?	250–383			Not raised			Not used	

171	.....do.....	.....do.....	B-17....	.....	Bored.....	705	701	260	....	....	Compressed air.	.....	.....	Factory.....	.....
172	Chino Land and Water Co.	.....do.....	B-17....	1899	Bored, 9½-inch (6 wells).	665	665	100-140	....	....	Artesian.....	.....	.....	Irrigation.....	103
172a	.....do.....	.....do.....	B-17....	1903	Bored, 9½ to 13 inch (2 wells).	665	665	100-140	....	....	.....do.....	.....	.....		
172b	.....do.....	.....do.....	B-17....	1903	Bored, 14-inch..	665	665	140	....	....	.....do.....	.....	.....		
172c	.....do.....	.....do.....	B-17....	1903	.....do.....	665	665	300	....	....	.....do.....	.....	.....		
173	.....do.....	.....do.....	B-16....	.....	Bored, 10-inch..	715	715	345	....	....	.....do.....	.....	.....	Domestic; stock.	5
173a	.....do.....	.....do.....	B-16....	.....	.....do.....	715	715	150	....	....	.....do.....	.....	.....		
174	H. W. Trayermuth.	Sec. 28, T. 1 S., R. 8 W.	B-14....	1897	Bored, 6-inch...	885	776	175	22	....	Wind.....	.....	.....	Domestic.....	.....
175	S. L. Crane.....	Sec. 29, T. 1 S., R. 8 W.	A-14....	1884	Bored, 7-inch...	865	777	90	....	....	.....do.....	.....	.....	.....do.....	.....
176	Mrs. M. E. Porter...	Sec. 28, T. 1 S., R. 8 W.	B-14....	1886	.....do.....	865	735	160	21	....	.....do.....	.....	.....	.....do.....	.....
177	Mrs. Tiegs.....	.....do.....	B-14....	.....	Bored, 10-inch..	835	749	341	....	....	Not raised.....	.....	.....	Not used.....	.....
178	J. O'Donnell.....	Santa Ana del Chino.	B-15....	.....	Bored, 7-inch...	840	752	174	....	....	Wind.....	.....	.....	Irrigation.....	.....
179	J. F. Mast.....	Sec. 28, T. 1 S., R. 8 W.	B-14....	.....	Bored, 10-inch..	870	764	150	21	....	.....do.....	.....	.....	Domestic; irrigation.	.....
180	M. E. Foster.....	.....do.....	C-14....	1895	Bored, 7-inch...	860	769	106	....	....	.....do.....	.....	.....	Domestic.....	.....
181	R. Reimers.....	.....do.....	B-16....	1894	.....do.....	770	737	65	....	....	.....do.....	75.00	60.00	.....do.....	.....
182	W. D. McCrosky....	.....do.....	B-16....	1891	Bored, 4-inch...	760	734	60	....	66	.....do.....	.....	.....	.....do.....	.....
183	McCrosky & Bowler	.....do.....	B-16....	.....	Bored, 10-inch..	745	727	400	....	....	.....	.....	.....	Not installed.....	.....
184	G. Y. Robertson....	.....do.....	B-16....	1898	.....do.....	720	715	160	19	67	Gas.....	250.00	1,000.00	Irrigation.....	† 40
185	George J. Weigle....	San Jose.....	A-16....	1899	Dug, 25 feet; bored, 9-inch, 280 feet.	765	743	305	....	....	.....do.....	500.00	1,000.00	.....do.....	† 50
186	R. M. Thurman.....	.....do.....	B-16....	1900	Bored, 9½-inch..	770	741	380	....	....	.....do.....	.....	.....	.....do.....	† 75
187	J. J. Allan.....	.....do.....	A-15....	1899	Bored, 10-inch..	780	744	346	....	....	.....do.....	600.00	1,500.00	.....do.....	† 75
188	B. F. Whipp.....	.....do.....	A-15....	1897	.....do.....	785	745	180	18	....	.....do.....	.....	.....	.....do.....	† 60
189	Humes & Gallup....	.....do.....	A-15....	1901	Bored, 9-inch...	785	745	379	....	....	.....do.....	.....	.....	.....do.....	† 60
190	N. W. Miller.....	.....do.....	A-15....	1898	Bored, 9½-inch..	790	753	245	....	....	.....do.....	440.00	1,230.00	.....do.....	† 50
191	C. G. Taylor.....	.....do.....	B-15....	1888	Bored, 7-inch...	790	752	275	....	....	Wind.....	.....	.....	Domestic.....	.....
192	Van Syke & Wickersham.	.....do.....	B-15....	1900	Bored, 13-inch..	805	755	434	19	....	Gas.....	1,300.00	1,700.00	Irrigation.....	† 76
193	Cobb, Walls, Landon & Co.	.....do.....	A-15....	1898	Bored, 10-inch..	800	760	400	....	....	.....do.....	1,000.00	2,100.00	.....do.....	† 60
194	Mrs. Edgar.....	.....do.....	A-14....	1903	.....do.....	845	773	.....	....	....	Wind.....	.....	.....	Domestic.....	.....
195	Sanford Ballou.....	.....do.....	A-14....	1884	Bored, 7-inch...	855	777	174	....	....	.....do.....	300.00	.....	.....do.....	.....
196	R. A. Krause.....	.....do.....	A-14....	.....	.....do.....	845	772	178	16	....	.....do.....	.....	.....	.....do.....	.....
197	T. E. Seagoe.....	.....do.....	A-14....	1890	.....do.....	830	Dry.	70	....	....	.....	.....	.....	No water.....	.....
198	J. J. Gorman.....	.....do.....	A-14....	1886	.....do.....	825	763	116	19	....	Wind.....	.....	.....	Domestic.....	.....
199	G. W. Harp.....	.....do.....	D-14....	.....	.....do.....	843	768	120	....	....	.....do.....	.....	.....	.....do.....	.....
200	E. Goytte.....	.....do.....	B-14....	1892	.....do.....	860	Dry?	78	....	....	.....	.....	.....	No water.....	.....
201	J. J. White.....	.....do.....	A-14....	1884	.....do.....	830	773	67	....	....	Wind.....	.....	.....	Domestic.....	.....
202	H. B. Hansen.....	.....do.....	A-14....	1884	.....do.....	825	771	57	....	....	.....do.....	.....	.....	Not used.....	.....
203	J. W. Snedaker.....	.....do.....	A-15....	.....	.....do.....	810	764	67	....	....	.....do.....	.....	.....	Domestic.....	.....
204	Charles Peterson...	.....do.....	A-15....	1896	.....do.....	820	763	73	....	....	.....do.....	.....	.....	.....do.....	.....
205	J. A. Walz.....	.....do.....	A-15....	1884	.....do.....	815	761	64	25	....	.....do.....	99.00	70.00	.....do.....	.....
206	W. M. Niebel.....	Santa Ana del Chino.	B-16....	.....	.....do.....	765	736	.....	22	....	.....do.....	.....	.....	.....do.....	.....

Wells in the foothill belt of southern California—Continued.

CUCAMONGA QUADRANGLE—Continued.

No. of well.	Owner.	Location.	Map location.	Year completed.	Class of well.	Elevation of surface (feet; approximate only).	Elevation of water (feet).	Depth of well (feet).	Solids per 100,000.	Temperature of water (°F.).	Method of lift.	Cost of well.	Cost of machinery.	Use of water.	Quantity of water (miner's inches).
207	V. DesNoyers	Santa Ana del Chino.	B-16	1899	Bored, 10-inch	730	723	224	17		Gas	$500.00	$800.00	Irrigation	†35
208	F. B. Troxell	do	B-16	1893	Bored, 4-inch	720	720	160	18	66	Artesian	300.00		Domestic; irrigation.	4
209	Louis Lockenour	do	B-17	1897	Bored, 7-inch	685	685	160	19	67	do			Irrigation	†3
210	J. Wire	do	B-17	1901	do	685	685	156			do	300.00		do	†30
211	George Beck	do	B-16	1901	Bored, 10-inch	710	710	220	18	69	do	425.00		do	†50
212	Mr. McKinley	do	B-16		do	710	710	146	20	69	do			do	†30
213	Mr. Marion	do	B-16	1899	Bored, 8-inch	720	720	198	19	69	do	400.00		do	†20
214	C. P. Brown	do	B-16		Bored, 9½-inch	730	722	160						Not used	
215	A. L. Tuft	do	B-16	1891	Bored, 10-inch	730	722	357				727.00		do	
216	Bowler Bros	do	B-17	1896	Bored, 7-inch	680	680	139	18	68	Artesian	200.00		Irrigation	†35
217	R. J. Stewart	do	B-17	1902	do	675	675	124			do			do	
218	Chino Land and Water Co.	do	B-17			665	665	180	17	68	do			Stock	
219	Mrs. F. Fabian	do	C-17	1897	Bored, 7-inch	670	670	255	19	68	do			Irrigation	†8
220	American Beet and Sugar Co.	do	C-17			675	675	140	20		do			Stock	
221	W. P. Brown	do	C-17	1897	Bored, 7-inch	685	685	311			do			Irrigation	
222	B. Ross	do	C-17		Bored, 10-inch	690	690	300	17	67	do			do	†20
223	S. H. Adams	do	B-16	1902	Bored, 7-inch	715	715	256	19	65	do	325.00		do	4
224	A. J. Morrison	do	B-17	1899	do	675	675	250	18	68	do	600.00		do	†20
225	Charles Mason	do	C-17		do	675	675	160			do			Stock; irrigation	
226	H. F. Haman	do	C-16	1900	do	758	728	347	17	65	Gas	500.00	750.00	Irrigation	†20
227	John Boesch, jr	do	C-16	1901	do	765	729	95			Wind	150.00	85.00	Domestic	
228	John Fintel	do	C-16	1901	do	775	731	68	22	63	Hand	75.00	20.00	do	
229	C. A. Mosher	do	C-15		do	790	739	80			Wind			do	
230		do	C-15		Dug, 4 by 5 foot	820	761	62	20	64	do			do	
231	F. W. Olmstead	Sec. 22, T. 1 S., R. 8 W.	C-13	1901	Bored, 10-inch	945	785	320			Gas	700.00	2,800.00	Irrigation	†20
232	Mrs. J. Cooley	San Jose	B-13	1896	Bored, 4-inch	930	782	170			Not raised			Not used	
233	Edward Gilson	do	B-13	1898?	Bored, 8-inch	940	809	200	17	62	Gas	300.00	600.00	Domestic	†7
234	M. Baldridge	do	B-13	1898	do	930	783	250			do	400.00	1,300.00	Irrigation	†10
235	W. N. Hendricks	do	B-12	1900	Bored, 10-inch	1,085	971	129			Not raised	250.00		Not used	
236	Stoddard, Hill & Tuttle.	do	B-12	1901	Bored, 14-inch	1,075	964	280			Compressed air.	600.00	1,600.00	Irrigation	40
236a	do	do	B-12	1901	do	1,075	964	265							

237	.....do.....	.....do.....	B-12....	1901	.....do.....	1,070	954	268	....	....	.....do.....	600.00	.....	.....do.....	†40
237a	.....do.....	.....do.....	B-12....	1901	.....do.....	1,070	954	270	....	....	.....do.....	.....	.....		
238	W. J. Warden	.....do.....	B-12....	1897	Bored, 10-inch..	1,065	952	187	10	....	Not raised.....		.....	Not used.....	.....
238a	.....do	.....do.....	B-12....	1897	.....do.....	1,065	952	115	10	....	.....do.....	1,900.00	.....	.....do.....	.....
238b	.....do.....	.....do.....	B-12....	1897	.....do.....	1,065	952	178	10	....	Gas.....		800.00	Irrigation.....	†20
239	John Miller.....	.....do.....	B-12....	1898	.....do.....	1,045	942	172	20	63	.....do.....	500.00	1,500.00	.....do.....	†15
240	George H. Miller....	.....do.....	B-12....	1899	.....do.....	1,085	972	200	21	64	.....do.....	500.00	1,000.00	.....do.....	†15
241	G. F. Ferris.....	.....do.....	B-11....	1892	Bored, 7-inch...	1,100	872	190	....	....	Wind.....	.....	.....	Not used.....	.....
242	San Antonio Water Co.	.....do.....	B-11....	.....	Bored, 12-inch..	1,121	966	558	....	....	.....	.....	.....	.....do.....	.....
242a	.....do.....	.....do.....	B-11....	.....	.....do.....	1,121	966	535	....	....	Electric motor..	.....	.....	Irrigation.....	†27
243	.....do.....	.....do.....	B-11....	.....	Bored.....	1,105	1,033	.....	....	....	.....do.....	.....	.....	.....do.....	†55
244	.....do.....	.....do.....	B-11,12..	.....	Dug, 7 by 10 foot.	1,100	1,031	.....	20	58	Not raised.....	.....	.....	Not used.....	.....
245	Bartlett Bros.....	.....do.....	B-11....	1899	Bored, 10-inch..	1,115	965	200	....	....	Gas.....	472.00	1,200.00	Irrigation.....	.....
246	H. R. Hawley	.....do.....	B-12....	.....	Bored.....	1,100	1,028	.....	....	....	Not raised.....	.....	.....	Not used.....	.....
247	Del Monte Irrigation Co.	.....do.....	B, C-11 .	1886	Bored, 7-inch...	1,135	1,065	275	....	62	Compressed air.	750.00			†60
247a	.....do.....	.....do.....	B, C-11 .	1902	Bored, 12-inch..	1,135	1,065	300	....	....	.....do.....	750.00			.....
248	.....do.....	.....do.....	C-11 ...	1902	.....do.....	1,130?	1,060?	300	....	62	.....do.....	750.00	15,000.00	Irrigation.....	†75
248a	.....do.....	.....do.....	C-11 ...	1903	Bored, 14-inch..	1,135?	1,065?	400	....	62	.....do.....	1,200.00			.....
249	.....do.....	.....do.....	B, C-11 .	1888	Bored, 7-inch...	1,130	1,060	225	....	....	.....do.....	700.00			35
249a	.....do.....	.....do.....	B, C-11 .	1888	.....do.....	1,135	1,065	160	....	....	.....do.....	550.00			.....
250	R. Bieley.....	.....do.....	C-11	1900	Bored, 10-inch..	1,155	1,071	117	....	....	Wind.....	.....	.....	Domestic; stock.	.....
251	George Jencks.....	Sec. 10, T. 1 S., R. 8 W	C-11	1901	.....do.....	1,230	1,089	175	....	....	Gas.....	400.00	600.00	Stock; irrigation	†5 †25
252	C. N. Brundage.....	.....do.....	B-12....	1897	Bored, 14-inch..	1,060	954	310	21	....	Electric motor..	250.00	1,200.00	Irrigation.....	
253	Garlock, Phillips & Loop.	San Jose.....	B-11....	1882	Dug, 8 by 10 foot, 50 feet; bored, 12-inch, 90 feet.	1,165	1,080	140	....	....	Steam.....	350.00	.....	.....do.....	†20
254	Del Monte Irrigation Co.	Sec. 9, T. 1 S., R. 8 W.	B-11....	1899	Dug, 5 by 8 foot, 106 feet; bored, 10-inch, 119 feet.	1,180	1,100	225	....	....	Electric motor..	600.00	1,700.00	.....do.....	†60
255	A. T. Currier.....	San Jose.....	A-11....	1895	Bored, 10-inch..	1,175	1,040	310	....	....	Gas.....	.....	.....	.....do.....	†15
256	L. Brosseau	.....do.....	A-12....	1894	Bored, 7-inch...	1,070	Dry.	98	....	....	.....	.....	.....		.....
257	Del Monte Irrigation Co.	Sec. 9, T. 1 S., R. 8 W.	B-11....	1899	Bored, 10-inch (3 wells).	1,190	1,110	225	....	....	Compressed air.	1,800.00	(a)	.....do.....	†50
258	Dr. M. B. Cambell...	San Jose.....	B-11....	.....	Bored.....	1,170	1,018	300	....	....	Gas.....	.....	.....	.....do.....	†20
259	John Beck.....	Sec. 9, T. 1 S., R. 8 W.	B-11....	.....	Bored, 7-inch...	1,215	1,100	.....	17	....	Wind.....	.....	.....	Domestic.....	.....
260	G. G. Charlton.....	.....do.....	B-10....	1899	Dug, 138 feet; bored, 9½-inch, 222 feet.	1,245	1,101	360	....	....	Steam.....	900.00	7,000.00	Irrigation.....	†30
261	A. W. Town.....	Sec. 4, T. 1 S., R. 8 W.	B-10....	1886	Bored, 6-inch...	1,240	1,090	320	....	....	Wind.....	.....	40.00	Domestic.....	.....
262	.....do.....	.....do.....	B-10....	1902	Bored, 12-inch..	1,280	1,105	320	....	....	Gas.....	1,000.00	2,000.00	Irrigation.....	15
263	C. Siever.....	.....do.....	B-10....	1895	Dug, 70 feet; bored, 9½-inch, 224 feet.	1,350	1,275	294	....	....	Tunnel.....	.....	.....	Not used.....	.....

a Connected with plants Nos. 247–249.

Wells in the foothill belt of southern California—Continued.

CUCAMONGA QUADRANGLE—Continued.

No. of well.	Owner.	Location.	Map location.	Year completed.	Class of well.	Elevation of surface (feet) approximate only.	Elevation of water (feet).	Depth of well (feet).	Solids per 100,000.	Temperature of water (°F.).	Method of lift.	Cost of well.	Cost of machinery.	Use of water.	Quantity of water (miner's inches).
264	Consolidated Water Co.	Sec. 3, T. 1 S., R. 8 W.	C-10	.....	Bored, 10-inch	1,300	1,204	200?	.....	.....	Flow into tunnel.	.....	.....	Domestic	† 70
265	Ontario Water Co.	do	C-10	1900	Bored, 10-inch (2 wells).	1,265?	1,224?	160	.....	.....	Compressed air.				
265a	do	do	C-10	1900	Bored, 10-inch	1,265?	1,224?	225	.....	.....	do	$2,400.00	$5,200.00	Irrigation	35
265b	do	do	C-10	1900	do	1,285?	1,225?	225	.....	.....	do				
265c	do	do	C-10	1900	do	1,270?	1,223?	225	.....	.....	do				
265e	do	do	C-10	1900	do	1,300?	.....	225	.....	.....	do	2,400.00			35
265	do	do	C-10	1901	do	1,305?	1,233?	200	.....	.....	do				
266	Citizens' Light and Power Co.	Sec. 33, T. 1 N., R. 8 W.	B-9	1903	Bored, 12-inch	1,370	1,217	385	21	64	Gas	1,400.00	3,000.00	Domestic; irrigation.	† 30
267	Martin Bros.	do	B-9	1899	Dug, 4 by 4 foot.	1,390	1,344	70	23	.....	Wind	200.00	125.00	Irrigation	† 1
268	do	do	B-9	1902	Dug, 3½ by 3½ foot, 106 feet; bored, 12-inch, 261 feet.	1,380	1,205	367	19	70	Gas	1,200.00	2,200.00	do	† 25
269	C. C. Johnson	do	B-9	1903	Dug, 3 by 3 foot.	1,345	1,217	130	21	.....	Wind	.....	.....	Domestic; irrigation.	.....
270	B. E. Street	do	B-9	1899	Dug, 100 feet; bored, 9-inch, 167 feet.	1,325	1,225?	267	.....	.....	Gas	800.00	200.00	Irrigation	2½
271	Claremont Cooperative Water Co.	Sec. 32, T. 1 N., R. 8 W.	A-9	1900	Bored, 12-inch	1,265	1,200	277	.....	.....	do	1,000.00	2,000.00	do	35
272	L. C. Pitzer	Sec. 5, T. 1 N., R. 8 W.	A-9	1903	Dug, 3 by 5 foot, 50 feet; bored, 14-inch, 370 feet.	1,270	1,200	420	.....	.....	do	1,500.00	3,500.00	do	† 35
273	Seth Richards Orange Grove Co.	do	A-9	1899	Bored, 10-inch	1,255	1,197	305	.....	.....	Compressed air.	(a)	.....	do	† 40
274	Prof. Sumner	do	A-10	1897	Bored, 12-inch	1,250	1,215	275	.....	.....	Gas	750.00	1,600.00	do	† 25
275	Schesler & Soaper	do	A-10	1902	Dug, 160 feet; bored, 10-inch, 148 feet.	1,275	1,107	308	.....	.....	do	900.00	2,000.00	do	† 15
276	John Joss	do	A-10	1898	Bored, 8-inch	1,185	1,044	205	21	.....	do	.....	.....	Domestic; irrigation.	† 15

277	Seth Richards Orange Grove Co.	Sec. 5, T. 1 S., R. 8 W.	A-10	1899	Bored, 10-inch	1,200	1,072?	293			Compressed air.	(*b) 12,400.00		Irrigation	
278	do	do	A-10	1899	do	1,190	1,068?	301			do				
279	do	do	A-10	1900	do	1,180	1,064?	322			do				
280	Kingsley Tract Water Co.	San Jose	A-12	1889	Bored, 6-inch	1,185	1,122	265	16		Gas	1,000.00	1,500.00	do	†30
282	O. W. Lorbeer	do	A-14	1902	Bored, 10-inch	860	775?	393			Steam	700.00		Laundry	
283	C. Seaver	do	A-13	1902	Bored, 7-inch	873	777	151			Wind	250.00	90.00	Domestic	1
284	Dr. A. R. Reed	do	A-12	1900	Bored, 9½-inch	1,010	952	200			do			do	
288	M. A. Williams	do	A-12	1896	Dug, 40 feet; bored, 7-inch, 120 feet.	955	923	160			Wind			do	
289	Irrigation Co. of Pomona.	do	A-12	1887	Dug, 4 by 6 foot, 50 feet; bored, 7-inch, 297 feet.	950	915	347			Electric motor	900.00	1,200.00	Irrigation	†60
290	Palomares Irrigation Co.	do	A-12	1886?	Bored, 7-inch	975	938	500			Wind	700.00		Domestic	
291	do	do	A-12	1886?	Dug, 50 feet; bored, 7-inch, 155 feet (2 wells).	995	948	205			Electric motor	400.00	2,450.00	Irrigation	†55
291a	do	do	A-12	1899	Bored, 10-inch	995	948	200			do				
292	Consolidated Water Co.	do	A-12	1904	Bored, 14-inch	985	935	223			do	*3,000.00		do	†60
293	do	do	A-12	1898	Bored, 10-inch	1,010	945	225			do	*3,000.00		Domestic	†30
294	Major Thomas	do	A-12	1892	Bored, 7-inch	1,020	960	200	21		Compressed air		3,000.00	Irrigation	†25
295	Consolidated Water Co.	do	A-12	1898	Bored, 10-inch	1,005	948	57			Electric motor	*3,000.00		Domestic	†27
295a	do	do	A-12	1897	Bored, 9-inch	1,005	952	223			do				
297	Chino Land and Water Co.	do		1889	Bored, 12-inch	990	950?	535			do	2,000.00?		Domestic; irrigation.	†60
298	Mr. Smith	do			Bored, 9-inch (3 wells).	975	925	229–321			Wind			Domestic	
299	Cathcart estate	do	A-12	1886?	Bored, 12-inch (5 wells).	980	912	300–600			Not raised			Not used	
300	J. W. Romick	do	B-11			1,125	969	200?			Wind			Irrigation	
301	Del Monte Irrigation Co.	Sec. 9, T. 1 S., R. 8 W.	B-11		Bored, 14-inch	1,180	1,090	200†			Not raised			Not used	

a Included in Nos. 277–279.

b Including No. 273.

Wells in the foothill belt of southern California—Continued.

POMONA QUADRANGLE.

No. of well.	Owner.	Location.	Map location.	Year completed.	Class of well.	Elevation of surface (feet)—approximate only.	Elevation of water (feet).	Depth of well (feet).	Solids per 100,000.	Temperature of water (°F.).	Method of lift.	Cost of well.	Cost of machinery.	Use of water.	Quantity of water (inches).
1	Currier Tract Water Co.	San Jose	M-13	1900	Bored, 10-inch	855	759	356			Electric motor	$1,200.00	$2,300.00	Irrigation	†70
2	M. L. Garcia	do	M-13	1902	Bored, 7-inch	850	780	100	22		Wind			Domestic	
3	L. R. Phillips	do	L-13	1899	do	800	754	56	22		do			do	
4	L. Monro	do	L-13		do	775	741	103			Not raised			Not used	
5	Mrs. S. L. Fryer	do	K-14		do	735	712	50			Wind			Domestic	
6	Fryer ranch	do	L-14	1900	Bored, 10-inch	738	710	190			Gas			do	
7	Earnest Whipp	do	K-14	1886	Bored, 7-inch	730	704	40	28		do			do	
8	J. M. Fryer	do	K-14	1895	do	720	695	44	25		Wind			do	
9	S. E. Hicks	do	J, K-14	1900	do	745	716	48	35		do			do	
10	J. M. Fryer	do	K-14		Dug, 3 by 3 foot	745	715	34			Hand			Domestic, stock	
11	Los Angeles County	do	K-14		Bored, 7-inch	780	748	55			Wind			Roads	
12	B. Linnastruth	do	N-13	1900	do	850	772	83	23		do			Domestic	
13	do	do	N-13	1897	do	862	792	75	16		do			do	
14	F. G. Herman	Sec. 30, T. 1 S., R. 8 W.	M, N-13		Bored, 8-inch	850	769	90	21		do			do	
15	Mrs. M. C. Blevett	San Jose	M-13		Bored, 7-inch	840	756	95			do			do	
16	A. M. Way	Sec. 34, T. 1 S., R. 9 W.	K-14	1900	do	695	673	61	24		do	70.00		do	
17	Stanley Bates	do	K-15		Dug, 4 by 6 foot, 11 feet; bored, 7-inch, 69 feet.	678	669	80	25		do			do	
18	Lynch ranch	do	K-15	1898	Bored	670	661	150	24		do			do	
20	D. H. Collins	do	K-15		Dug, 8-foot diameter.	657	656	3	25		do			do	
21	M. T. Scanlon	do	K-15	1901	Dug, 2 foot diameter.	662	659	12	170		Hand			Stock	
22	Antone Rayes	Sec. 4, T. 2 S., R. 9 W.	J-14		Bored, 7-inch	650	639	70	23		Wind			Domestic	
23	R. T. Currier	Sec. 9, T. 2 S., R. 9 W.	J-16, 17		Bored, 8-inch	600	583	86	32		do			do	
24	K. H. Dorsey	San Jose	K-14	1898	Bored, 7-inch	705	682	81			Steam	*1,250.00		Irrigation	50
25	do	do	K-14	1898	Bored, 10-inch	705	682	65			do				
28	Sam Lee Co.	do	L-14		do	755	732	149			Gas			do	†40
29	do	do	L-14		do	755	732	149			Flows 23 feet below surface.				

30	D. D. Ross	do	M-14	1880	Bored, 6-inch	840	771	75	25		Wind			Domestic		
31	Robert Allen	do	M-14	1900	Bored, 7-inch	830	780	90	23		do			do		
32	Pomona Brick Co	do	M-14		do	815	771	80			do			do		
33	Mr. Barnhardt	do	N-14		do	810	769	57	24		do			do		
34	Miss Sarah Dundas	do	N-15		Dug, 6 by 6 foot	800	774	40	29		do			do		
35	D. Hawkins	do	N-14	1885	Bored, 7-inch	840	775	96			do			Irrigation		
36	James Gallaway	do	N-15	1902	do	802	770	70	28		do	115.00	210.00	Domestic; irrigation.		
37	F. C. Westphal	do	N-15	1900	Dug, 4 by 4 foot	790	769	26	22		do			Domestic		
38	Mrs. L. R. Matthews	do	N-15	1899	Bored, 10-inch	800	762	250			Gas	450.00	1,800.00	Irrigation		†80
39	Hill & Wickson	do	N-14	1899	do	815	757	245			do	425.00		do		†75
40	P. R. Perris	do	N-15	1902	Dug, 3 by 3 foot	790	766	25	30		Hand			Domestic		
41	W. C. McGuire	do	N-14	1897	Bored, 8-inch	825	772	110	23		Wind			do		
42	Kerckhoff - Cuzner M. & L. Co.	do	N-13	1885	do	860	783	166			Not raised			Not used		
43	D. R. Kelsey	do	N-13	1902	Bored, 10-inch	880	800	161			Gas	325.00	1,650.00	Irrigation		†25
44	S. J. Bromley	do	N-12	1895	do	935	909	100	18		Wind			Domestic		
45	R. Vejar	do	N-11, 12	1886	Bored, 7-inch	1,046	972	260	16		do	800.00		do		
46	Frank Vejar	do	N-11	1897	do	1,045	968	115	16		do			do		
47	P. T. Yorba	do	M, N-11	1900	do	1,045	964	120	24		do			do		
48	James Fulton	do	N-11	1898	Dug, 4 by 4 foot, 95 feet; bored, 12-inch, 205 feet.	1,070	977	300			Gas			Domestic; irrigation.		†30
49	J. Steves	do	N-11	1895	Bored 7-inch	1,085	985	128	70		do	250.00	450.00	do		†10
50	Lordsburg Water Co.	do	N-11	1899	Dug, 5 by 5 foot, 120 feet; bored, 10-inch, 180 feet.	1,100	981	300			do	800.00	2,200.00	Irrigation		†33
51	William Bosbyshell	do	N-11	1900	Bored, 10-inch	1,050	965	340			do		1,475.00	Domestic; irrigation.		†50
54	B. F. Whipp	do	N-13	1897	Bored, 7-inch	900	840	61	20		Wind			Domestic		
55	Orange Grove Avenue Water Association.	do	N-13	1900	Dug, 5 by 7 foot, 62 feet; bored, 10-inch, 278 feet.	920	904	340	14		Electric motor	1,700.00	1,600.00	Irrigation		†65
56	Mel Campbell	do	N-13	1897	Bored 7-inch	920	908	250	16		Gas	900.00	1,350.00	Domestic; irrigation.		†40
57	do	do	N-13	1896	do	920	908	180			do			Irrigation		
59	Mrs. L. T. Alkire	do	N-13		do	900	862	60			Wind			Domestic		
60	Frank Vejar	do	M-12	1880	do	990	972	48	24		do			Stock		
61	Palomares ranch	do	M-12		Dug, 4 by 4 foot	995	978	20	32		Hand			Domestic		
62	Keiser Bros	do	M-11	1899	Bored, 10-inch	1,030	960	360			Gas			Irrigation		†50
63	Lordsburg Water Co.	do	M-11	1900	Dug, 4 by 5 foot; bored, 10-inch.	1,065	982	202			do	400.00	1,800.00	Domestic; irrigation.		†25
64	S. L. Gross	do	N-11	1902	Bored, 12-inch	1,090	990?	100?			Electric motor		*4,000.00	do		
65	do	do	N-11	1902	Bored, 14-inch	1,090	990?	100?			do					†50
66	H. J. Nichols	do	N-11		Bored, 7-inch	1,115	976	162	18		Wind			Domestic		
67	F. H. Massey	do	N-11	1898	Bored, 10-inch	1,165	977	200+			Not raised			Not used		
69	Mesa Water Co	Sec. 5, T. 1 S., R. 8 W.	N-10	1903	Dug, 4 by 6 foot, 140 feet; bored, 12-inch, 180 feet.	1,230	1,129	320			Electric motor					†30

Wells in the foothill belt of southern California—Continued.

POMONA QUADRANGLE—Continued.

No. of well.	Owner.	Location.	Map location.	Year completed.	Class of well.	Elevation of surface (feet)—approximate only.	Elevation of water (feet).	Depth of well (feet).	Solids per 100,000.	Temperature of water (°F.).	Method of lift.	Cost of well.	Cost of machinery.	Use of water.	Quantity of water (miner's inches).
71	R. E. Winter	Sec. 5, T. 1 S., R. 8 W.	N-9	1901	Bored, 12-inch	1,240	1,110	300			Gas			Domestic; irrigation.	†15
72	R. A. Wallace	Sec. 6, T. 1 S., R. 8 W.	N-10		Bored, 7-inch	1,152	997	165			do			Domestic	5
73	Duarte Mutual Irrigation and Canal Co.	Azuza Duarte	C-8	1901	Dug, 9 by 6 foot.	598	553	218			Steam	*$20,000.00		Domestic; irrigation.	64
74	J. H. Maddock	do	C, D-7	1899	Dug, 2¾ by 3¾ foot.	695	582	120	28		Gas	*2,000.00		do	†15
75	Duarte Mutual Irrigation and Canal Co.	do	D-7	1902	Dug, 6 by 6 foot.	690	612	130			Not raised			Not used	
76	A. C. Thompson	do	D-8	1900	Dug, 6 by 8 foot.	650	614	80			Steam	*7,000.00		Irrigation	†100
77	D. H. Thrasher	do	C-8	1898	Dug, 4 by 6 foot, 235 feet; bored 12-inch, 26 feet.	550	315	261			Not raised	1,200.00		Not used	
78	West Duarte Development Co.	do	B-7	1903	Dug, 4 by 6 foot, 118 feet; bored, 8-inch, 92 feet.	620	566	210			Gas			Domestic; irrigation.	†15
79	Duarte Mutual Irrigation and Canal Co.	do	B-8		Bored, 10-inch	610	Dry.	200						No water	
80	E. D. Northup	do	B-8, 9	1895	do	475	306	222	26		Wind	1,400.00		Domestic	
81	W. S. Newhall	do	D-7	1900	Dug, 4 by 5 foot.	680	610	100			Steam			Irrigation	†25
82	Orange Avenue Land and Water Co.	La Puente	D-12	1903	Bored, 12-inch	420	293	262			do	1,075.00	$3,400.00	do	
83	Irwindale Land and Water Co.	do	D-12	1899	Dug, 4 by 6 foot, 130 feet; bored 12-inch, 72 feet.	428	294	202	25		do	*5,000.00		do	†65
84	J. F. Irwin	Sec. 16, T. 1 S., R. 10 W.	D-11		Dug, 120 feet; bored, 10-inch, 60 feet.	424	294	180			Gas			do	†35
85	D. L. Allen	Sec. 17, T. 1 S., R. 10 W.	C-11		Bored, 7-inch	390	287	115	28		Wind				

86	Vineland irrigation district plant.	Sec. 9, T. 1 S., R. 10 W.	C-11	1898	Dug, 104 feet; bored, 12-inch, reduced to 10-inch, 370 feet.	400	294	474			Steam	3,000.00		Domestic; irrigation.	†100
87	Vineland school district.	Sec. 18, T. 1 S., R. 10 W.	C-11		Bored, 7-inch	382	288	140	27		Wind			Domestic	
88	C. N. Buck	do	B-11		do	372	285	100	28		do			do	
89	Washington Bunch.	Sec. 7, T. 1 S., R. 10 W.	B-11	1895	Dug, 3 by 3 foot.	380	289	100			Not raised			Not used	
90	Baker ranch	Sec. 18, T. 1 S., R. 10 W.	B-11		Bored, 7-inch	370	284	80			Wind			Domestic	
91	G. Nebbir	Sec. 12, T. 1 S., R. 11 W.	B-11		do	352	282	75	28		do			do	
92	Cypress Avenue Water Co.	La Puente	E-11	1903	Dug, 4 by 6 foot, 170 feet; bored, 12-inch, 130 feet.	466	296	300			Steam	935.00?		Irrigation	
93	P. C. Basher	do	F-12	1900	Dug and bored, 10-inch.	485	315	304	29		Gas	400.00	900.00	do	†15
94	William Overholtzer	do	E-12	1900	Bored, 10-inch	465	300	300	30		do	800.00	2,175.00	Domestic; irrigation.	23
95	E. C. Mullendor	do	E-12	1903	Dug, 4 by 6 foot.	430	304	128			Installing plant.				
96	G. F. Chamberlain	do	E-12, 13.	1900	Dug, 3 by 3 foot.	422	306	118	22		Wind			Domestic	
97	Griffith Bros	do	E-14	1892	Bored, 7-inch	422	294	130	40		do			do	
98	Edward Fickewirth.	do	C-12		Bored, 10-inch	352	307	300?	26		do			do	
99	do	do	D-15	1900	Bored, 12-inch	362	312	850							
100	do	do	D-15	1900	do	362	302	287			Not raised			Not used	
101	do	do	D-15	1900	do	362	302	307			do			do	
102	E. J. Baldwin	do	A-15		Driven, 2-inch	278	263	24	31		Hand			Domestic	
103	Los Angeles County.	do	A-14		Bored, 7-inch	275	263	60	26		Wind			Roads	
104	C. N. Bassett	do	A-14	1899	Bored, 12-inch	315	289	125			Steam	2,500.00	2,400.00	Irrigation	135
105	E. M. Haddock	do	A-14	1900	Bored, 9½-inch	305	275	125	27		do			do	†90
106	E. J. Baldwin	do	B-14		Bored, 7-inch	335	292	58	26		Wind			Domestic	
107	Los Angeles County.	do	C-16		do	320	302	58	53		do			Roads	
108	do	do	B-15		do	295	280	65	38		do			do	
109	E. J. Baldwin	do	B-16		Bored, 9-inch	295	286	22			Not raised			Not used	
110	L. F. Lewis	do	B,C-16		Bored, 10-inch	312	288	300			do			do	
111	J. W. Hudson	do	C-17	1880	Bored, 7-inch	330	305	39	41		Wind			Domestic	
112	Joseph Ferara	do	C-17		Dug, 5 feet diameter.	342	320	25	75		do			do	
113	Rowland ranch	do	D-17		Bored, 7-inch	360	326	60	47		do			do	
114	San Pedro, Los Angeles and Salt Lake R. R.	do	D-17	1903	Bored, 14-inch	380	347	300	74		Gas			Engines	
115	Rowland school district.	do	D-17		Dug, 4 by 4 foot.	350	332	22	71		Hand			Domestic	
116	L. Didier	do	E-17	1893	Dug, 30 feet; bored, 7-inch, 70 feet.	370	347	100	107						
117	H. Heinze	do	C-16	1896	Bored, 7-inch	323	297	127	59		Wind			Domestic	
118	E. Rambaud	do	C-16	1900	Dug, 4 by 4 foot.	340	310	42	78		do			do	
119	George Cross	do	C-16		Bored, 7-inch	342	311	93	57		do			do	

Wells in the foothill belt of southern California—Continued.

POMONA QUADRANGLE—Continued.

No. of well.	Owner.	Location.	Map location.	Year completed.	Class of well.	Elevation of surface (feet)—approximate only.	Elevation of water (feet).	Depth of well (feet).	Solids per 100,000.	Temperature of water (°F.).	Method of lift.	Cost of well.	Cost of machinery.	Use of water.	Quantity of water (miner's inches).
120	George Cross	La Puente	D-17	1902	Bored, 9½-inch	340	328	148	70		Not raised	$350.00		Not used	
121	William Rowland	do	D-17	1901	Bored, 9⅝-inch	355	331	165			Electric motor	272.50?	$3,500.00	Irrigation	
122	do	do	D-17	1901	do	355	331	165			do	272.50		do	† 104
123	do	do	D-17	1901	do	355	331	165			do	272.50		do	
124	do	do	D-17	1901	do	355	331	165			do	272.50		do	
125	do	do	D-17	1901	do	356	326	500			do			Domestic; irrigation.	† 15
126	H. L. Armstrong	do	C-17	1902	Bored, 8-inch	320	315	120	58		Gas		1,200.00	Irrigation	† 80
127	do	do	C-17	1902	do	320	315	290			do				
128	do	do	C-17	1902	do	320	315	160			do				
129	B. F. Rowland	do	E-17		Bored, 7-inch	370	348	26			Wind			Domestic	
131	Rowland estate	do	D-15		do	345	307	73	31		Hand			do	
132	E. J. Baldwin	do	C-14		do	340	295	80			Wind			do	
133	Robert Rowland	do	F-17		Dug, 5-foot diameter.	390	365	26			do			do	
134	A. H. Yorba	do	F-17	1893	Bored, 7-inch	430	383	84	46		do			do	
135	B. Yorba	do	F-17		do	395	367	50	60		do			do	
136	J. P. Edwards	do	D-17	1901	do	365	330	42	49		do			do	
137	M. Vasquez	do	D-16	1902	Dug, 4 by 4 foot	346	324	30	56		Hand			do	
138	Jose Cota	do	D-16	1903	do	338	324	17	61		do			Domestic; irrigation.	
139	William Aschenbrenner.	do	F-12, 13	1900	Bored, 10-inch	475	325	300			Not raised			Not used	
140	W. G. Kerchkoff	do	G-13	1900	do	545	385	400			Electric motor	*3,000.00		Irrigation	† 15
141	G. O. Shouse	do	H-12	1903	Bored, 12-inch	660	553	400	86		Wind			Domestic	
142	do	do	H-12	1900	do	550	550	90			Not raised			Not used	
143	C. H. Cannon	San Jose	J, K-11		Bored, 10-inch	850	Dry.	180						No water	
144	William Ferry	do	J-11	1900	do	855	657	222			Not raised	723.00		Not used	
145	Macneil ranch	Azusa Dalton	G-9		Bored, 12-inch	602	326	600?			do			do	
146	L. G. Parker	Sec. 1, T. 1 S., R. 10 W.	G-10		do	615	344	294			do			do	
147	A. Jackson	San Jose Addition.	H-10	1900	Dug, 3 by 6 foot	745	646	110	65		Gas			Irrigation	† 10
148	Hauser Bros. Co.	do	H-10	1900	do	700	Dry.	224						No water	
149	Sidney Deacon	do	J-11		Bored, 12-inch	825	694	160			Steam			Not used	
150	do	do	J-11		do	825	695	155			Not raised			do	

151	H. Rees	San Jose	J-11	1895	Bored, 7-inch	830	Dry.	162						No water		
152	A. R. Evans	La Puente	F-13	1899	Bored, 10-inch	485	330	400			Compressed air.	1,300.00	2,700.00	Irrigation		†20
153	Mr. Davison	Sec. 31, T. 1 N., R. 9 W.	H-9	1900	Dug, 4 by 6 foot.	698	652	70	27		Not raised			Not used		
154	B. F. Taylor	San Jose Addition.	H-10	1899	Dug, 5-foot diameter.	720	653	86	23		do			do		
155	West Middleton	do	I-10		Dug, 3 by 6 foot.	810	Dry.	116						No water		
156	William Bowring	do	I-10	1900	Dug, 4 by 4 foot.	810	682	158	35		Not raised	1,000.00		Not used		
158	J. W. Cook	Sec. 20, T. 1 N., R. 9 W.	I-7	1897	Dug, 4 by 6 foot.	1,050	1,036	70	49		do			do		
159	John Engelehardt	do	I-7	1899	do	1,080	Dry.	200				2,000.00		No water		
160	I. R. Miller	do	I-7	1897	do	1,070	1,058	64	76		Not raised			Not used		
161	J. F. Shank	Sec. 31, T. 1 N., R. 9 W.	H-9	1899	Bored, 10-inch	700	Dry.	190						No water		
162	G. S. Thomas	do	H-9	1898	do	738	628	185	34		Gas			Domestic		7
163	W. H. Hall	do	H-9	1899	Dug, 3 by 6 foot.	730	624	112	32		do			Irrigation		
164	A. B. Rodgers	do	H-9	1899	Dug, 4 by 6 foot.	725	620	151			Not raised	1,000.00		Not used		
165	J. H. Hommell	do	H-9	1900	Bored, 10-inch	700	580	190			Gas	300.00	950.00	do		7
166	Jacob Boerlin	do	H-9	1903	Dug, 4 by 4 foot.	740	713	33	48		Hand					
181	Pomona Land and Water Co.	San Jose	N-12	1894	Bored, 7-inch	1,000	945	325			Electric motor	1,200.00	2,200.00	Irrigation		†60
182	Irrigation Co. of Pomona.	do	N-12	1888	Bored, 9½-inch and 8-inch.	960		950			Compressed air.	6,000.00	1,500.00	do		†60
183	do	do	N-12	1887	Bored, 7-inch	955		440			do	900.00		do		†15
185	Mr. Strause	Sec. 8, T. 2 S., R. 9 W.	I-17	1896	Dug, 3 by 3 foot.	555	537	20	55		Hand			Domestic		
186	Paton & Co	Sec. 17, T. 2 S., R. 9 W.	I-17	1903	Bored, 10-inch	570	532	60	31		Gas	300.00	1,500.00	Irrigation		†77
187	McClintock, Lee & St. Clair.	La Puente	I-17	1902	do	550	518	100			do	250.00	1,360.00	do		†62
188	Mrs. E. M. Dailey	do	I-17	1897	Bored, 8-inch	540	517	55			do			do		†60
189	Mr. Swan	do	I-17	1902	Bored, 7-inch	550	517	55			Wind			Domestic		
190	G. W. Bowman	do	H-17	1903	Dug, 4 by 6 foot.	535	514	38	46		Gas	350.00	1,100.00	Irrigation		†80
191	L. Snodgrass	do	H-17	1894	Bored, 7-inch	510	487	40	56		Wind			Domestic		
192	S. M. Bowers	do	H-16	1903	Dug, 6 by 8 foot.	555	527	40			Gas		600.00	Irrigation		†12
193	B. F. Bowers	do	H-16	1903	do	560	530	36	55		do			do		5
194	William Rowland	do	H-17	1890	Dug, 3 by 3 foot.	540	502	45	52		Wind			Domestic		
195	W. H. Swan	do	H-17	1896	Dug, 3½ by 3½ foot.	530	505	30			do			do		
196	G. W. Bowman	do	H-17	1891	Bored, 4-inch	530	502	120	52		do			do		
197	F. M. Howell	do	H-17	1902	Dug, 8 by 8 foot.	515	495	40			Gas			Irrigation		†25
198	Joseph Monroy	do	I-16	1896	Dug, 3 by 3 foot.	540	528	14	55		Wind			Domestic		
199	James Huff	San Jose	M-11	1899	Bored, 10-inch	1,010	966	280	21		do	600.00	75.00	do		
200	Covina Irrigating Co	do	M-11	1898	Bored, 10-inch (5 wells).	995?	950?	240–400			Compressed air.	7,000.00	7,000.00	Irrigation		†125
201	do	do	M-11	1899	do	995?	950?	240–300			do					
202	J. S. Soto	do	M-11	1884	Bored, 7-inch	1,020	972	50	17		Wind			Domestic		
203	A. A. Macias	do	M-11	1899	Dug, 3½ by 3½ foot.	1,015	973	43			do			do		
204	Mrs. Dolores de Carrión.	do	L-11	1898	Dug, 5 by 5 foot, 40 feet; bored, 10-inch, 40 feet	975	951	80			Gas	400.00	700.00	Domestic; stock.		†10

Wells in the foothill belt of southern California—Continued.

POMONA QUADRANGLE—Continued.

No. of well.	Owner.	Location.	Map location.	Year completed.	Class of well.	Elevation of surface (feet)—approximate only.	Elevation of water (feet).	Depth of well (feet).	Solids per 100,000.	Temperature of water (°F.).	Method of lift.	Cost of well.	Cost of machinery.	Use of water.	Quantity of water (miner's inches).
205	Margaret Flemming.	San Jose	M-11	1897	Bored, 7-inch	1,042	1,002	275			Compressed air.	$600.00	$3,500.00	Irrigation	†25
206	H. C. Fisher	do	M-11	1894	do	1,049	1,004	375			Gas	700.00	450.00	do	†7
207	Stratton & Hayes	Sec. 1, T. 1 S., R. 9 W.	M-10	1891	do	1,135	1,037	170			do	275.00	500.00	do	†10
208	A. Baker & Son	Sec. 36, T. 1 N., R. 9 W.	M-9	1902	Bored, 12-inch	1,215	1,031	347			do	1,259.00	1,250.00	Domestic	8
209	do	Sec. 1 T. 1 S., R. 9 W.	M-9	1902	do	1,175	995	450			do	1,500.00	5,200.00	Irrigation	†40
210	N. L. Sparks	Sec. 36, T. 1 N., R. 9 W.	M-9	1901	Dug, 157 feet; bored, 12-inch, 167 feet.	1,185	1,001	324			do	1,100.00	4,000.00	do	†30
211	Williams Bros	San Jose	L-9	1900	Dug, 136 feet; bored, 10-inch, 139 feet.	1,090	920	275			do			do	†30
212	A. Swerdfeger	do	L-10	1902	Bored, 12-inch	1,080	915	300			do			do	†35
213	W. T. Michael	do	L-9	1897	do	1,120	1,035	200	31		do	750.00	3,000.00	do	†25
214	Partin & Allman	do	M-9, 10	1900	do	1,130	980	350			do	225.00	2,250.00	do	†30
215	Michel, Bixby, Kroeger & Co.	Sec. 1, T. 1 S., R. 9 W.	M-9	1902	do	1,140	980	339			do		1,750.00	do	†35
216	James A. Johnstone.	San Jose	M-10	1902	Bored, 14-inch	1,095	970	333			do		4,000.00	do	†35
217	L. S. Thacker	do	M-10	1893	Bored, 7-inch	1,085	970	152			Wind	225.00	125.00	Domestic	
218	F. H. Paine	Sec. 36, T. 1 N., R. 9 W.	M-8	1902	Bored, 12-inch	1,305	1,238	148			Gas	600.00	800.00	Irrigation	†8
219	E. W. Hart	San Jose	L, M-10	1901	do	1,095	972	300	17		do	1,000.00	1,200.00	do	†20
220	W. S. Carson	do	L-10	1896	Bored, 7-inch	1,070	972	124	20		Wind	175.00	60.00	Domestic	
221	Laverne Irrigating Co.	do	M-10	1903	Bored, 12-inch	1,095	971	230			Gas	840.00		Irrigation	†35
222	L. C. Meredith	do	L-10	1895	do	1,060	967	265			do	600.00	1,700.00	do	†30
223	R. C. Callander	do	L-10	1900	Bored, 10-inch	1,065	920	233	25		do	260.00	950.00	do	†20
224	Frostless Belt Water Co.	do	L-10	1902	do	1,042	948	254	23		do	1,000.00	1,800.00	do	†30
225	George E. Coleman and Laverne Irrigating Co.	do	L-10	1900	do	1,050	985	270			do		1,200.00	do	†52

226	W. G. Doughty	San Jose Addition.	L-9	1900	do	1,055	920	246			Steam	1,000.00	2,500.00	do	†52
227	L. S. Thacker	do	L-9	1899	Bored, 12-inch	1,050	920	245			Gas	700.00	2,200.00	do	†20
228	San Dimas Irrigation Co.	do	L-9	1900	do	1,055	913	264	24		do		3,500.00	do	†40
229	Johnston & Rutherford.	San Jose	L-10	1901	do	1,065	921	216			do	1,000.00	3,500.00	do	†30
230	Covina Irrigating Co.	San Jose Addition.	L-9	1904	do	1,045	915	270			do	500.00	1,500.00	do	
231	Glendora and Azusa Water Co.	Sec. 35, T. 1 N., R. 9 W.	L-9	1900	do	1,065	912	376			Electric motor			do	†45
231a	do	do	L-9	1901	do	1,065	912	530			do			do	†110
232	Western Water and Power Co.	do	L-9	1900	do	1,070	915	514	24		Steam	9,387.44	13,995.32	do	†125
233	do	do	L-9	1901	do	1,075	915	546	24		do			Domestic; irrigation.	
234	Citrus Belt Water Co.	do	L-9		Bored	1,070	913					*4,000.00			
235	San Dimas Irrigation Co.	San Jose	L-10	1898	do	1,005	954	220			Steam			Irrigation	†45
236	New Deal Land and Water Co.	do	L-10	1898	Bored, 10-inch	1,020	953	170			Gas	305.00	564.00	do	†18
237	San Dimas Irrigation Co.	do	L-10	1902	Bored	1,025	955	300			do	700.00	2,500.00	do	†30
238	David Teague	do	L-11	1898	Bored, 10-inch	980	850	260			do			do	†20
239	J. C. Marquart	Sec. 32, T. 1 N., R. 9 W.	I-9		Dug, 4 by 4 foot	830	740				Not raised			Not used	
240	S. R. Deacon	Sec. 33, T. 1 N., R. 9 W.	J-9	1903	Bored, 7-inch	840	770	102	30		do			do	
241	Columbia Land and Water Co.	San Jose Addition.	K-9, 10	1897	Bored, 12-inch (2 wells).	940	880	180	21		Gas	1,200.00	2,500.00	Irrigation	†50
242	Covina Irrigating Co.	do	K-10	1889	Bored, 12-inch	930	880	150			do	2,000.00	3,000.00	do	†42
244	James Walker	do	K-10	1902	do	1,005	905	200			Steam			do	†50
245	Artesian Belt Water Co.	do	L-10	1898	do	1,010	909	386			do			do	†35
245a	do	do	L-10	1899	do	1,010	909	210			do			do	†35
246	E. Firth	do	K-9								Gas			do	†20
247	Valentine Peyton	San Jose	N-10	1905	Dug, 166 feet; bored, 12-inch, 436 feet.	1,145	997?	636			Steam	*14,000.00		do	
248	Live Oak Water Co.	Sec. 6, T. 1 S., R. 8 W.	N-9		Bored, 12-inch	1,275	1,123	383			Electric motor	*4,000.00		do	†30
249	Laverne Land and Water Co.	Sec. 5, T. 1 S., R. 8 W.	N-10	1900	Bored, 12-inch (2 wells).	1,235	1,075	300?			Gas	1,800.00	5,000.00	do	†55
250	Charles Alley	San Jose	M-10		Bored, 10-inch	1,120	975	175			Wind			Stock	
251	Azusa Irrigating Co.	San Jose Addition.	K-10	1899	Dug, 4 by 10 foot, 104 feet; bored, 12-inch, 200 feet.	1,000	903	304?			Not raised			Not used	
252	George Smith	La Puente	G-12		Bored, 7-inch	550	333	220			do			do	
253	W. A. Sproul	Azusa Dalton	F-8		Dug, 3 by 3 foot	645	557	88			Gas	*2,000.00		Irrigation	†15

Wells in the foothill belt of southern California—Continued.

POMONA QUADRANGLE—Continued.

No. of well.	Owner.	Location.	Map location.	Year completed.	Class of well.	Elevation of surface (feet)—approximate only.	Elevation of water (feet).	Depth of well (feet).	Solids per 100,000.	Temperature of water (°F.).	Method of lift.	Cost of well.	Cost of machinery	Use of water.	Quantity of water (miner's inches).
254	Azusa Agricultural Water Co.	Azusa Dalton	E-8		Dug, 90 feet; bored, 15-inch, 120 feet.	690	600	210			Not installed				
255	do	Sec. 23, T. 1 N. R. 10 W.	F-7		Dug, 6 by 8 foot.	700	630	100			Electric motor		*$5,000.00	Irrigation	† 50
256	William Rowland	La Puente	D-17	1902	Bored, 10-inch	350	260	90			Wind			Domestic; stock	
257	F. Bowers	do	H. I-17	1900	Bored, 7-inch	525	502	40			do			Domestic	
258	S. E. Hicks	San Jose	K-14		do	700	664	78			do			do	
259	Los Angeles County	do	K-14		do	705	667	55			do			Roads	
260	Irrigation Co. of Pomona.	do	N-12		Bored, 9½-inch	950	912	51			Not raised			Not used	
261	Mrs. M. Myers	do	N-12		do	950	913	97			Wind			Domestic	
262	A. T. Currier	Los Nogales	J-15	1898-1902	Bored, 9½-inch (6 wells).	625	625	80-115			Artesian			Irrigation	80
263	San Pedro, Los Angeles and Salt Lake R. R.	do	K-15		Bored, 7-inch	655	655	32			do			Not used	1

PASADENA QUADRANGLE.

1	Mrs. Titus	Santa Anita	I-8	1892	Bored	690	674?	558			Wind	$4,000.00		Domestic; irrigation.	
2	G. Hutchinson	do	I-8	1890	Bored, 8-inch	713	651	230			do			Domestic	
3	J. P. Butler	do	I-8	1894	Bored, 7-inch	720	630	127			Gas	175.00	$480.00	Domestic; irrigation.	3
4	J. P. Butler	do	I-8	1902	do	718	658	150			do	375.00	500.00	do	5
5	F. E. Chapman	do	H. I-8	1888	do	725	655	104			do	200.00	50.00	do	3
6	Mrs. Black	do	H-8			712	654	100?							
7	R. H. Schoemaker	do	H-8	1900	Bored, 10-inch	722	652	130?			Gas	200.00	100.00	Domestic; irrigation.	
8	J. B. Bonnadie	do	H-8	1897	Bored, 7-inch	723	649	102			do	110.00	350.00	do	
9	James MacAdam	do	H-8	1893	do	740	651	150			do	400.00	1,000.00	do	3
10	Mr. Merwin	do	H-8			735	657	95							

11	Mrs. L. C. Scoville	do	H-8	1896	Bored, 7-inch	741	669	175						Domestic; irrigation.	
12	I. McCollum	San Pasqual	H-8			785	663	151			Wind			do	
14	G. W. Clark	Santa Anita	H-8	1897	Bored, 7-inch	776	651	151			Wind; gas			do	2
15	H. L. Moses	San Pasqual	H-8	1895	do	790	664	200			Gas	350.00	220.00	do	†2
16	H. C. Rice	do	H-8	1902	do	798	658	196			do	260.00	435.00	do	4
17	S. V. Harkness	do	H-8	1902	Bored, 12-inch	787	670	272			Not raised	265.00		Not used	
21	Mr. Miles	Santa Anita	I-7			817	652	225			Gas		400.00		
22	Andrew Ruedy	do	I-7	1884		813	646	168			Wind		255.00	Domestic	
23	C. A. Hobart	do	J-7	1899	Bored, 7-inch	705	610	129				165.00		Stock	
24	Pasadena Brick Yard.	do	G-9	1901	do	750	694	750			Not raised			Not used	
25	City of Monrovia	do	K-8		Bored, 10-inch	645	628	540			Compressed air		5,000.00	Domestic; irrigation.	†25
26	do	do	K-8	1902		645	633	386			do			do	
27	do	do	K-8			645	633	386			do			do	†115
28	C. F. Lee	San Pasqual	H-7	1902	Bored, 7-inch inside of 10 inches.	796	656				Gas	470.00	1,450.00	do	11
29	Mr. Garvin	do	H-8		Bored, 10-inch	784	657	290			Not raised			Not used	
30	E. A. Bonine	Santa Anita	I-8	1881	Bored, 7-inch	749	664	113			Gas	115.00	750.00	Domestic; irrigation.	2
31	P. S. MacKay	do	I-8	1902	Bored, 8-inch	722	635	250			Compressed air	525.00	1,065.00	Irrigation	†15
32	Mrs. Baker	do	I, J-8	1896	Bored, 7-inch	700	619	86			Wind	100.00	70.00	Domestic; irrigation.	
33	Mrs. Humphrey	do	I, J-8			690	622	90+							
34	Mr. Ackerman	do	I-8		Bored	710	630	149							
35	F. C. Ballinger	do	I-8	1882?		686	645	55			Wind				
37	Titus ranch	do	I-9			635	633	153			Electric motor			Irrigation	
41	I. N. Van Nuys	do	I-9		Bored, 10-inch	633	623	482			Flows into tunnel.			do	15
42	do	do	I-9		Bored, 7-inch	633	623	280			Siphon			do	16
43	do	do	I-9		do	633	623	71			do			do	10
44	do	do	I-9		do	633	623	25			Not raised			Not used	
45	do	do	I-9		do	633	623	25			do			do	
46	do	do	I-9		do	633	623	25			do			do	
47	do	Sec. 35, T. 1 S., R. 12 W.	I-9								Tunnel				6
48	William Blake	San Pasqual	F-8	1900	Dug, 3½ feet diameter.	812	748	65			Wind		55.00		
49	F. W. Richmond	do	F-8	1896	Dug, 30 feet; bored, 30 feet.	790	743	60?			do			Domestic	
50	Charles Wilson	do	F-9	1900	Dug, 3½ feet diameter.	775	745	33			Hand	100.00		do	
51	Pasadena and Pacific power house.	do	F-9		Bored, 10-inch	750	719								
52	Raymond station	do	F-9		Dug, 12 feet diameter.	750	728	24							
53	Euclid Avenue Water Co.	do	F-9	1901	Bored, 12-inch	750	727	126			Electricity			Irrigation	26

Wells in the foothill belt of southern California—Continued.

PASADENA QUADRANGLE—Continued.

No. of well.	Owner.	Location.	Map location.	Year completed.	Class of well.	Elevation of surface (feet—approximate only).	Elevation of water (feet).	Depth of well (feet).	Solids per 100,000.	Temperature of water (°F.).	Method of lift.	Cost of well.	Cost of machinery.	Use of water.	Quantity of water (miner's inches).
54	Oak Knoll ranch	San Pasqual	G-9	1899	Dug, 41 feet; bored, 12-inch, 148 feet.	752	709	189			Electric motor	*$1,500.00		Irrigation	†48
55	do	do	G-9		Dug, 50 feet; bored, 7-inch, 100 feet.	752	709	150			Gas			do	15
56	Hurlbut place	do	F-9		Bored, 7-inch	816	745	1,306						Not used	
57	L. A. & T. T. Cooper	Sec. 34, T. 1 N., R. 12 W.	H-9	1901	Bored, 12-inch, 600 feet; 10-inch, 200 feet.	600	338	800				3,700.00		do	
58	Garvey Water Co.	Sec. 35, T. 1 N., R. 12 W.	H-9		Bored, 10-inch	634	614	360			Gas			Irrigation	†30
59	do	Santa Anita	H-9		Bored, 12-inch	700	620	360			Electric motor			do	
60	do	do	H-9			700	620	350			do			do	
64	do	do	H-9		Bored, 7-inch	660	650	60						Not used	
65	Mr. Baker	San Pasqual	E-9			740	717	32						Domestic	
66	F. J. Culver	do	E-9	1899	Dug, 5-foot diameter.	748	720	59			Electric motor				8
67	do	do	E-9			752	719	50							
68	Mr. Reed	do	F-8		Bored, 12-inch	860	734	200+			Gas			Domestic; irrigation.	†9
70	Mr. Cooper	do	E-7			845	759	90			Wind				
71	Weymouth & MacAdams.	do	E-7	1902	Bored, 12-inch	850	746	457						Not used	
72	Mr. Stone	do	E-5, 6		Dug, 6 by 4 foot	1,040	954	106							
73	Mr. Lloyd	do	E-6		Dug, 3 by 4 foot	1,035	952	85			Wind				
74	MacDonald & Staats	do	E-6		do	995	865	134							
75	K. G. Hommel & Co.	do	F-5	1900	Dug, 5 by 4 foot	1,185	984	210			Gas	500.00	$1,200.00	Not used	
76	Mountain View Cemetery.	do	F-5	1902	Dug, 4-foot diameter.	1,185	940	265			do	1,000.00	1,200.00	Irrigation	†8
78	Rubio Canyon Land and Water Association.	do	G-5	1902	Bored, 12-inch	1,150	965	280			do	850.00	4,300.00	Domestic; irrigation.	23
80	Mr. Meer	do	G-6			1,060	884	300							
81	Fair Oaks ranch	do	H-6			1,090	800	300?							
82	do	Santa Anita	I-6	1902	Bored, 12-inch	1,010	770	330			Gas	825.00	3,000.00	Irrigation	†22

83	Mr. Craig	do	H-7	1899	Bored, 11-inch	855	635	632			Electric motor		950.00	Domestic; irrigation.	20
84	Thomas B. Bishop	Sec. 15, T. 1 S., R. 12 W.	G-12	1901	Bored, 12-inch	465	279	190						Not used	
85	W. N. Murray	do	H-12	1899	Bored, 10-inch	425	290	265			Gas	499.50	1,327.50	Irrigation	†10
86	John Cazauraug	Sec. 21, T. 1 S., R. 12 W.	F-13			440	416				Wind			do	
88	H. E. Farmen	Sec. 22, T. 1 S., R. 12 W.	G-13	1902	Bored, 12-inch	410	298	266			Gas				
89	do	do	G-13		do	408	299	455							
90	do	do	G-13		do	402	296	450							
91	Mr. Howe	Sec. 27, T. 1 S., R. 12 W.	H-13		Bored, 10-inch	383	331	100							
92	P. G. Mason	Sec. 23, T. 1 S., R. 12 W.	I-13	1902	Bored, 5½-inch	350	286	74			Not installed	56.00			
93	Martin Haig and J. & E. Parker.	Potrero Grande	J-13		Bored, 7-inch	267	267	424			Compressed air, artesian.			Irrigation	
94	do	Sec. 24, T. 1 S., R. 12 W.	I-13		do	285	260	686			Compressed air			do	†60
95	do	Potrero Grande	J-13		do	267	262	263						Not used	
96	do	Sec. 26, T. 1 S., R. 12 W.	J-13			400	300	160						Domestic	
97	Garvey ranch	Potrero Grande	J-13	1898	Bored, 12-inch	267	267	775			Compressed air, artesian.	3,000.00		Irrigation	150
98	do	do	J-13	1899	Bored, 10-inch	267	267	425			Artesian	1,050.00		do	
99	do	do	J-13	1895	Bored, 7-inch	267	267	214			do	550.00		do	
100	do	do	J-14	1888	do	265	257	75			Wind				
101	E. J. Baldwin	do	J-14			260	260	100			Artesian, wind			Stock; irrigation	
102	F. E. Wilson	Sec. 24, T. 1 S., R. 12 W.	I-13	1901	Bored, 6-inch	287	267	36			Wind			Domestic	
103	A. J. B. Immel	do	I-13	1902	Bored, 10-inch	297	270	203			Gas	400.00	400.00	Irrigation	12
104	F. Wyman	do	I-13		Bored, 7-inch	300	269	60			Hand			Domestic	
105	H. McCoy	do	I-13		do	311	274	51			Wind			do	
106	Mrs. C. E. Mitchell	do	I-13		do	312	274				do	225.00		do	
107	John McClain estate.	Sec. 14, T. 1 S., R. 12 W.	I-12	1896	do	342	273	130			do			do	
108	John McKay	do	I-12	1896	do	337	273	110			do	130.00	75.00	do	
109	Judge Northrup	Sec. 23, T. 1 S., R. 12 W.	I-12, 13		do	330	273				do				
110	W. W. Gaines	Sec. 24, T. 1 S., R. 12 W.	I-13	1900	do	317	274	100			do			Domestic	
111	John McClure	do	J-13	1890	Dug, 3-foot diameter.	320	282	44							
112	do	do	J-13		do	320	280	51							
113	Isabell McLeod	Sec. 13, T. 1 S., R. 12 W.	I-12	1867	Dug, 4 by 6 foot, 50 feet; bored, 10-inch, 30 feet.	330	285	80						Not used	
114	Pasadena city farm.	Sec. 14, T. 1 S., R. 12 W.	H-12		Bored, 7-inch	387	287	150			Wind, horse-power.			Domestic	
115	G. Purcell	Sec. 11, T. 1 S., R. 12 W.	I-11		Dug, 3-foot diameter.	416	378	45			Wind			do	

Wells in the foothill belt of southern California—Continued.

PASADENA QUADRANGLE—Continued.

No. of well.	Owner.	Location.	Map location.	Year completed.	Class of well.	Elevation of surface (feet—approximate only).	Elevation of water (feet).	Depth of well (feet).	Solids per 100,000.	Temperature of water (°F.).	Method of lift.	Cost of well.	Cost of machinery.	Use of water.	Quantity of water (gallons per day).
117	Warde Bros.	Sec. 13, T. 1 S., R. 12 W.	I 12		Bored, 7-inch	328	278	80			Wind				
118	A. E. McClintock	Sec. 19, T. 1 S., R. 11 W.	I 12	1876	do	310	269	52			do		$130.00	Domestic	
119	Harry E. Rose	Sec. 7, T. 1 S., R. 11 W.	J 11	1900	Bored, 12-inch	380	289	350			Steam	$*7,000.00		Irrigation	75
120	do	do	J 11	1900	do	380	289	650							
121	Reed ranch	Sec. 18, T. 1 S., R. 11 W.	I 12		Bored, 7-inch	330	262				Wind			Domestic	
122	J. Rudel winery	Sec. 7, T. 1 S., R. 11 W.	J 11	1890	do	398	300	300			Compressed air	500.00	1,500.00	Domestic; irrigation.	40
123	Margaret Tecklenborg.	Sec. 9, T. 1 S., R. 12 W.	H 11	1901	Bored, 12-inch	468	293	311			Gas	650.00	1,500.00	do	†10
124	A. C. Weeks	Sec. 10, T. 1 S., R. 12 W.	G, H 11		do	480	295	294			do	700.00	1,700.00	do	
125	E. E. McCollough	Sec. 11, T. 1 S., R. 12 W.	H 11	1899	Bored, 10-inch	430	330	451			do	*4,000.00		Irrigation	
126	S. F. Wnest	Sec. 9, T. 1 S., R. 12 W.	G 11	1899	Bored, 9½-inch	565	325	470			do	1,000.00	2,000.00	do	12
127	H. Hellman	Sec. 7, T. 1 S., R. 11 W.	J 11		Bored, 7-inch	402	301	166			Wind			Domestic	
128	J. W. Barton	San Francisquito	K 11		Bored, 10-inch	375	285	105			do			do	
129	Mr. Lukens	do	L 11		Bored, 7-inch	370	283	95							
130	Mr. Olmstead	do	L 11		do	350	284				Wind, gas			Domestic; irrigation.	
131	Mrs. Olmstead	do	L 11			351	283				Wind			do	
132	Mr. Meek	do	L 11		Bored, 7-inch	342	281				Gas				
133	T. S. Stucker	do	L 11	1895	do	326	280	50			Wind	45.00	60.00	Domestic	
134	J. A. Lucas	do	L 11	1893	do	320	281	180			do			Domestic; irrigation.	
135	J. C. Hanman	do	L 11		do	322	282	70			do				
136	E. J. Baldwin	do	L 11		do	306	280	27			Hand			Domestic	
137	C. E. Gidley	do	L 11, 12	1891	do	314	277	48			Wind			do	
138	J. W. Cushing	do	K 11		do	328	284	60			do			do	
139	J. Murray Craig	do	K 12		do	306	276	80			do			do	
140	John Abell	do	K 12		do	298	278	30			do			do	
141	J. A. Saw	do	L 12		do	282	269	50			do	50.00	170.00	do	

142	J. H. Jones	do	K-12	1890	do	286	273	26					do		
143	F. A. Forst	do	K-12		do	292	274			Wind					
144	Savannah cemetery	Sec. 18, T. 1 S., R. 11 W.	K-12		do	305	267	45		do			Irrigation		
145	Annie P. Adams	San Francisquito	K-12	1897	do	326	284	78		do	130.00		Domestic		
146	C. W. Cook	Sec. 18, T. 1 S, R. 11 W.	K-12		do	340	284	90		do					
147	do	do	K-12		Dug, 60 feet; bored, 10-inch, 26 feet.	345	285	86		Horsepower			Irrigation		
148	Andrew Lassmull	Sec. 19, T. 1 S., R. 11 W.	J-13	1888	Bored, 7-inch	284	260	64		do		40.00			
149	C. E. Negus	Potrero Grande	J-13	1899	Dug, 4 foot diameter.	250	247	6		Hand			Domestic		
150	Mr. Olmstead	do	J-14		Dug, 2 foot diameter.	249	246	6							
151	E. J. Baldwin	do	K-13		Dug, 2½ by 2½ foot.	248	242	10		Hand			Domestic		
152	T. P. Herbert	do	L-13	1901	Driven, 2-inch	255	247	18		do			do		
153	E. J. Baldwin	do	L-13		Bored, 7-inch	260	248	23		Gas			Domestic; irrigation.		
154	L. A. Crawford	Sec. 21, T. 1 S., R. 11 W.	L-13		do	270	256	18		Wind			Domestic		
155	F. Crab	do	L-13		Bored, 10-inch	273	256	130		Gas			Irrigation		
156	W. R. Dodson	do	L-13	1897	Bored, 12-inch	280	263	153		do	200.00	1,000.00	do		
157	Southern Pacific R. R.	San Francisquito	L-12	1870	Bored, 7-inch	285	261	480		Steam			Engines		6
158	G. H. Kallmayer	Sec. 21, T. 1 S., R. 11 W.	L-13	1895	do	280	261	30		Wind			Domestic		
159	Los Angeles County	San Francisquito	L, M-13		do	280	259			do			Stock		
160	Nicholas Smith	do	M-13	1879	do	280	261	40		do					
161	Newman ranch	Sec. 28, T. 1 S., R. 11 W.	M-13		do	270	257	80		do			Domestic		
162	Mountain View school.	Potrero de Felipe Lugo.	M-13		do	280	260	24		do			do		
163	Los Angeles County	San Francisquito	M-13		do	284	261	30		do			Stock		
164	T. D. Andrews	Potrero de Felipe Lugo.	M-13, 14		do	275	257	25		Hand			Domestic		
165	Newman ranch	Sec. 22, T. 1 S., R. 11 W.	L-13		Bored, 10-inch	280	261	140		Gas			Irrigation		
166	Hop Yuck Co	Sec. 28, T. 1 S., R. 11 W.	L-14		Dug, 3 by 3 foot	258	250	9		Hand			Domestic		
167	Com Song Co	Potrero Grande	L-14		do	254	247	8					do		
168	W. L. Hinman	do	L-14	1900	Bored, 7-inch	248	241	35		Wind	40.00		do		
169	Sam Gee Co	do	L-14			245	240	7		Hand			do		
170	J. R. Allen	Potrero de Felipe Lugo.	L-15	1899	Bored, 7-inch	245	238	42		Wind	42.00		do		
171	J. D. Durfee	do	L-15		do	242	236	40		do			do		
172	Charles Flickett	do	M-15		do	249	238	29		do			Domestic; irrigation.		
173	Jackson Frees	do	N-14		do	290	267			do			Domestic		
174	do	do	N-14		Bored, 12-inch	292	266	95		Gas	450.00	2,000.00	Irrigation		
175	A. E. Shugg	do	M 14	1887	Bored 7-inch	280	260	48		Wind			Domestic		

Wells in the foothill belt of southern California—Continued.

PASADENA QUADRANGLE—Continued.

No. of well.	Owner.	Location.	Map location.	Year completed.	Class of well.	Elevation of surface (feet—approximately).	Elevation of water (feet).	Depth of well (feet).	Solids per 100,000.	Temperature of water (°F.).	Method of lift.	Cost of well.	Cost of machinery.	Use of water.	Quantity of water (gallons per day).
176	William Elliot	Potrero de Felipe Lugo.	N-14		Bored, 7-inch	271	255	25			Wind				
177	W. S. Parker	do	M 15		do	252	242	38			Hand				
178	G. Castino	do	M 15	1900	Bored, 1½-inch	250	238	18			do			Domestic	
179	Lou Gan	Potrero Grande	L-15		Dug, 2 by 2 foot	223	218	70			do			do	
180	H. C. Yerby	do	K 15	1898	Bored, 7-inch	220	213	100			Wind			do	
181	Puente school	Paso de Bartolo	K, L 15		do	215	207				Hand			do	
182	S. A. McClean	do	K 16		do	215	204	50			Wind, horse-power.			Domestic; irrigation.	
183	E. L. Baldwin	do	K 16		Dug, 2 by 2 foot	210	204	7			Hand			Domestic	
184	G. Puima	do	K 16		do	200	194	7			Wind			do	
185	M. M. Zunica	do	J 16		Dug, 4 by 4 foot	210	197	14			Hand			do	
186	Mr. Botha	do	K 16		Dug, 3 by 3 foot	195	187	10						do	
187	Joe Contraro	do	J 16		do	195	187	9			Hand			do	
188	O. Fizzette	do	J 16		Bored, 4-inch	190	182	45			do			do	
189	W. Hyler	do	J 16		Driven, 2½-inch	190	180	12			do				
191	Rincon Irrigation Co.	do	L-17	1901	Bored, 10-inch	220	208	165			Gas	$*2,200.00		Irrigation	
192	R. Garvey	Sec. 27, T. 1 S., R. 11 W.	N-14	1902	Bored, 7-inch	290	265	60			Wind	70.00		Domestic	
193	T. J. Wiggins	Sec. 26, T. 1 S., R. 11 W.	N-14		do	280	262	57			Hand			do	
194	do	do	N 14	1898	Bored, 12-inch	270	266	104			Steam	225.00	$1,000.00	Irrigation	100
195	E. J. Baldwin	Sec. 35, T. 1 S., R. 11 W.	N 15			290	258	50			Wind			Domestic	
196	Mr. Harvey	Sec. 3, T. 2 S., R. 11 W.	M 15		Dug, 3 by 3 foot	300	251	50			Hand			do	
198	John Petriti	Paso de Bartolo	L 17		Dug, 4 by 4 foot	220	193				Wind				
199	Joseph Eady	do	K 17		Bored, 4-inch	205	192	36			do			Domestic	
200	Paso de Bartolo Water Co.	do	K 16		Bored, 10-inch (3 wells).	200	200	300			Artesian			Irrigation	
201	do	do	K 16		Bored, 10-inch	200	188	350			Steam		2,500.00	do	
202	Mr. Pellett	do	K 16			200	187	20			Hand			Domestic	
203	Mrs. Phoebe Barnett	do	K 16		Bored, 7-inch	195	181	33			Wind			do	
204	California Domestic Water Co.	San Francisquito	N 13	1902	Bored, 15-inch, 580 feet; 12-inch, 420 feet.	295	274	1,000			Compressed air.			Irrigation	

205	Thomas McMichael	do	N-13		Bored, 7-inch	292	266	50			Wind			Domestic		
206	E. T. Hargrave	do	N-13		do	296	267	72			do					
207	W. Richards	do	M-13		Bored, 10-inch	286	264	114			Steam			Domestic		
208	A. C. Drake	do	N-13		Bored, 7-inch	290	262	45						Irrigation		
209	do	do	N-13		Bored, 12-inch	308	270	140			Gas			Domestic		
210	A. E. Nelson	do	N-12	1902	do	318	274	127			Hand	200.00		do		
211	B. A. Benjamin	do	N-12		do	318	274	93			Wind, gas			Domestic; irrigation.		
212	John Hayes	Sec. 14, T. 1 S., R. 11 W.	N-12	1901	do	316	273	112			Gas	700.00	2,500.00	Irrigation		
213	do	San Francisquito	N-12	1901	do	315	272	130			do					
214	James Freer	do	M-13	1897	Bored, 7-inch	292	267	46			Wind, horse-power.			Domestic		
215	M. Metcalf	do	M-13	1900	do	290	267	45			Wind			do		
216	J. S. Killian	do	N-12		Bored, 12-inch	325	272	130			Steam			Irrigation		
217	do	do	N-12		do	325	272	100			do			do		
218	do	do	N-12		do	325	272	100			do			do		
219	do	do	N-12		do	325	272	100			do			do		
220	John Hayes	do	N 12		Bored, 8-inch	302	273	46			Gas		300.00	Domestic		
221	D. C. Nidever	do	M 12	1897	Bored, 10-inch	296	267	101			Steam	*1,200.00		Irrigation	100	
222	R. E. Damer	do	M 12		Bored, 7-inch	300	269	60			Wind			Domestic		
223	B. W. Daucer	do	M-12		do	302	269				Hand			do		
224	Daucer Bros	do	M-12	1898	Bored, 10-inch	305	269	103			Steam	*1,300.00		Irrigation		
225	P. F. Cogswell	do	N-13	1892	Bored, 12-inch	305	272	137			Gas			do		
226	Yock ranch	do	N 12		Bored, 7-inch	320	274	50			Hand			Domestic		
227	Piercy ranch	do	N 11	1898	Bored, 12-inch	335	277	129			Steam		2,500.00	Irrigation		
228	do	do	N-11	1894	Bored, 10-inch	335	277	107			do					
229	D. F. Pearson ranch	do	N 11	1896	Bored, 12-inch	325	273	150			Gas	300.00	1,400.00	do	150	
230	do	do	N-11	1895	do	325	273	114			do	250.00				
231	Sumar ranch	do	N-10	1899	Dug, 4 by 4 foot.	344	277	72			Hand			Domestic		
232	Stucker estate	do	L, M 11		Bored, 4-inch	312	274	40			Wind			do		
233	M. A. Papon	do	M 11		Bored, 7-inch	320	276	46			do			do		
234	W. Snoddy	do	M 10		do	340	289	52			do			do		
235	do	do	M 10	1899	Bored, 12-inch	345	291	247			Steam	525.00	1,700.00	Irrigation		
236	Alvarida Water Co.	Santa Anita	M 10	1899	do	385	325	209			Gas		4,000.00	do	25	
237	A. J. Averell	do	M-7	1899	Dug, 4 by 7 foot, 218 feet; bored, 10-inch, 178 feet.	511	305	396			Steam?		16,000.00	do	25	
238	Mr. Boyd	do	M-7		Bored, 12-inch	530	310	350						Not used		
239	Harry R. Stocker	do	M 7	1902	Dug, 4 by 6 foot.	550	514	49			Gas?		1,150.00	Irrigation	†18	
240	E. J. Baldwin	do	K-8		Bored, 7-inch	630	625	270			Compressed air, artesian.					
241	do	do	K 8		Bored, 10-inch	630	627	450			do			Irrigation		
242	do	do	K 8		Bored, 7-inch	610	611	300			Artesian			do		
243	do	do	K 8		do	618	608	130			Hand			Domestic		
244	do	do	K 8		do	618	612							Not used		
245	do	do	K-8		do	585	585	225			Artesian					
246	do	do	K-8	1902	Dug, 4 by 6 foot, 71 feet; bored, 7-inch, 289 feet.	614	594?	480			Steam, air			Irrigation	†40	

Wells in the foothill belt of southern California—Continued.

PASADENA QUADRANGLE—Continued.

No. of well.	Owner.	Location.	Map location.	Year completed.	Class of well.	Elevation of surface (feet—approximate only).	Elevation of water (feet).	Depth of well (feet).	Solids per 100,000.	Temperature of water (°F.).	Method of lift.	Cost of well.	Cost of machinery.	Use of water.	Quantity of water (inches in Hebbe).
247	F. J. Baldwin	Santa Anita	K 8		Bored, 7-inch	600	601	300			Artesian			Domestic	
248	do	do	K 8		do	614	614	300			do				
249	do	do	K 8		do	605	606	300			do			Domestic	
250	do	do	K 8		do	600	601	300							
251	do	do	K 8		do	596	599	300			Artesian			Stock	
252	do	do	K 8		do	593	595	300			do			do	
253	do	do	K 8		do	590	594	300			do			Not used	
254	do	do	M 7		Dug, 6 by 6 foot.	570	528	57			Gas			Irrigation	†60
255	do	do	M 6		Dug, 3 by 5 foot.	750	709	62							
256	T. E. Yerxa	do	M 7		Dug, 4 by 6 foot.	745	577	178			Gas	$1,300.00	$1,400.00	Irrigation	10
257	I. C. Pegler	do	M 6	1897	do	777	569	236			do		3,000.00	do	10
258	Sierra Madre Water Co.	do	M 7	1900	Dug, 5 by 6 foot, 136 feet; bored, 12-inch, 223 feet.	675	552	359			Gas (2 plants)	2,500.00	6,000.00	do	20
259	Graves & Bean	San Pasqual	G 9		Bored	750	701	204			Flows into tunnel.				
260	do	do	G 9		do	752	703	256			do			Irrigation	†20
261	do	do	G 9		do	755	703	212							
262	Sunny slope ranch	San Anita	J 9		Bored, 7-inch	618	615	117			Wind				
263	do	do	J 9		do	620	616	160						Not used	
264	do	do	J 9		do	618	604	210						do	
265	do	do	J 9		do	618	604	200+			Tapped below surface.				
267	J. S. Maderis	do	J 8	1901	do	645	621	200			Gas	350.00	550.00	Domestic; irrigation.	
268	Fred W. Elleby	do	J 8		Bored, 8-inch	648	614	112			do			do	11
269	E. Messenger	Sec. 9, T. 1 S., R. 12 W.	G 11	1900	Bored, 9½-inch	525	305	340			Gas?	600.00	1,495.00	do	12
270	F. J. Culver	San Pasqual	E 9		Bored, 7-inch	768	725	105							
272	M. M. Langford	do	F 8		do	800	734	73			Wind			Domestic	
273	E. J. Baldwin	do	K 8		do	650					Compressed air			Irrigation	
274	Joe Aguire	Paso de Bartolo	J 17		Dug, 3½ by 3½ foot.	175	164	11			Hand			Domestic	
275	A. Genen	do	J 11		Bored, 4-inch	175	185	34			do			do	
276	T. P. Passons	do	J 17		do	185	173	43						do	
277	A. Dixon	do	J 17		do	180	160	64			Hand			do	

278	D. A. Sugg	do	I-17		Dug, 3½ by 3½ foot.	180	161	20			do				
279	K. Cohn	San Antonio	I-17	1899	Bored, 12-inch	220	180	245			Steam			Irrigation	200
280	do	do	H-17		Bored, 7-inch	198	154	146			Wind			Domestic	
281	W. C. Rushing	do	H-17	1902	Bored, 5½-inch	200	148	57			Hand	45.00		do	
282	Vail, Gates & Co.	do	H-17		Bored, 12-inch	195	150	500			Electric motor			Irrigation	100
283	Bicknow & White	do	G-16		Bored, 7-inch	205	133	100			Wind			Domestic	
284	Mr. Pendina	do	F-16		do	200	154	65			do			do	
285	George Peterson	do	E-16		do	200	158	100			do			do	
286	E. G. Green	do	D-16		Bored, 8-inch	200	150	65			do			do	
287	Mr. Shaffinger	Sec. 31, T. 1 S., R. 12 W.	E-15			310	175	165			do			do	
288	I. W. Hellman	Sec. 32, T. 1 S., R. 12 W.	F-15	1903	Bored, 10-inch	285	157	250			Gas	512.00	300.00	do	
289	J. M. Clyman	Sec. 31, T. 1 S., R. 12 W.	E-15		Bored, 2-inch	320	220	115			Wind			do	
290	P. H. Matthews	Sec. 32, T. 1 S., R. 12 W.	E-15		Bored, 7-inch	295	170	335			do			Domestic; irrigation.	
291	Calvary Cemetery	San Antonio	E-16		Bored, 10-inch	220	160	213			Gas			Irrigation	
292	F. Escallier	do	D-16	1903	Bored, 12-inch	225	152	171			Not installed				
293	L. Pilaria	do	D-16		Bored, 7-inch	280	160	140						Not used	
294	G. W. Shields	Sec. 1, T. 2 S., R. 13 W.	D-16		do	315	165	180			Wind			Domestic	
295	F. C. Randolph	Sec. 31, T. 1 S., R. 12 W.	D-15		do	330	224	110			do			do	
296	B. J. Nettleton	San Antonio	D-16		do	215	157	120			do			do	
297	I. O. O. F. cemetery	Sec. 1, T. 2 S., R. 13 W.	C, D-16	1899	Bored, 9-inch	250	144	248			Gas	500.00		Irrigation	†3
301	C. Spect	Los Angeles city	B-12		Bored, 7-inch	333	303	38			Wind			Domestic	
302	Eli Taylor	do	B-12	1894	do	395	335	54			do	100.00		do	
303	Armour Packing Co.	do	B-12	1902	Bored, 8-inch	340	310	55			Electric motor			do	†3
304	Mrs. Norman	do	A-11		Bored, 7-inch	340	328	40			Wind			do	
305	Mary Everett	do	A-11		Dug, 5 by 5 foot	450	420	29						Not used	
306	Mrs. E. Dupuis	do	B-11	1885	Bored, 8-inch	350	327	9			Wind			Domestic; irrigation.	
307	Mr. Mackay	do	B-11	1880	Bored, 7-inch	360	310	20			do			Not used	
308	Chinese vegetable garden.	San Rafael	A-11		Dug, 4 foot diameter.	340	331	11			Hand			Domestic	
309	L. Shilker	do	A-11	1890	Bored, 8-inch	360	344	40			Wind			do	
310	Fraternal Club	do	A-11		Dug, 2 by 2 foot	375	344	34			do			do	
311	F. Douillard	do	A-11		Dug, 6 by 6 foot	450	446	10			do			do	
312	Joe Hunter	do	A-10		Dug, 4 by 4 foot	375	366	21			Hand			do	
313	V. & E. Sentona	do	A-10		Bored, 7-inch	370	353	30			Wind			do	
314	Samuel Hunter	do	A-10		do	375	357	43			do			do	
315	L. Salzgeber	do	A-11	1902	Bored, 12-inch	350	336	97			Gas	150.00	1,400.00	Irrigation	†90
316	J. W. Cook	do	A-10		Bored, 7-inch	400	361	60			Wind			Domestic	
317	Mr. Glassale	do	A-10			410	359	90			do			do	
318	Jack Greggians	do	A-10		Bored, 7-inch	390	372	60			do				
319	Conrad Winter	do	A-10		do	390	381	45			do			Domestic	
320	Silas Hollenbeck	do	A-8		Dug, 4-foot diameter.	540	512	46			do			do	
321	A. Workman	do	A, B-8, 9.	1901	Bored, 12-inch	600	535	171			Gas	427.00	1,000.00		8

Wells in the foothill belt of southern California—Continued.

PASADENA QUADRANGLE—Continued.

No. of well.	Owner.	Location.	Map location.	Year completed.	Class of well.	Elevation of surface (feet—approximate only).	Elevation of water (feet).	Depth of well (feet).	Solids per 100,000.	Temperature of water (°F.).	Method of lift.	Cost of well.	Cost of machinery.	Use of water.	Quantity of water (inches).
322	A. Workman	San Rafael	A-9		Dug, 8 by 8 foot.	530	499	50							
323	I. Brooks	do	B-9	1903	Bored, 8-inch	510	492	140						Not used	
324	Cromwell Galpin	do	B-9	1899	Bored, 7-inch	540	510	66			Gas	$120.00	$600.00	Irrigation	6
325	S. G. Spear	do	A-10	1887	Dug, 6 by 6 foot.	450	395	70			Wind			Domestic	
326	A. Glassell	do	B-9	1880	Bored, 7-inch	495	495	80			Artesian	80.00		Domestic; irrigation.	
327	do	do	B-9		Bored, 7-inch (2 wells).	490	490	210, 140			do			do	
329	O. D. Nagle	do	A-10	1901	Dug, 4 by 4 foot.	395	380	75			Wind, gas			do	
330	W. R. White	do	C-8, 9	1899	Bored, 7-inch	550	510	142			Gas			do	1
330a	do	do	C-8, 9	1902	Bored, 12-inch	550	510	113			do			do	1 20
331	J. A. Gates	do	C-8		Bored, 12-inch (2 wells).	550	510	144			do			Irrigation	20
332	G. W. Benson	do	B-8		Dug, 3-foot diameter.	590	530	100			Wind			Domestic	
333	P. Young	do	B-8	1901	Bored, 12-inch	570	511	140			Gas			Irrigation	8
334	J. L. Hickson	do	C-8		Bored, 7-inch	640	610	86			do			do	
335	L. F. Meyers	do	C-8		Bored, 9-inch	590	540	78			Wind			Domestic	
336	A. M. Torrey	do	C-8, 9		Bored, 8-inch	650	596	86			do			do	
337	C. E. Thom	do	A-7		Bored, 12-inch	635	555	170			Gas			Domestic; irrigation.	16
338	McWhorter Bros.	do	A-10		Bored, 7-inch	375	351	50			Wind			Domestic	
339	E. Leavitt	do	A-7	1902	Dug, 4 by 4 foot, 100 feet; bored, 9½-inch, 147 feet.	625	438	247			Gas	500.00	1,500.00	Domestic; irrigation.	14
340	F. M. Beers	do	A-8		Dug, 3 by 4 foot.	585	435	180			do			do	14
341	Dr. Horace Wing	do	A-8	1900	Dug, 4 by 4 foot, 105 feet; bored, 14-inch, 82 feet.	565	459	187			do			Irrigation	9
342	Mr. Lukens	do	A-8		Dug, 4 by 5 foot, 153 feet; bored, 12-inch, 115 feet.	605	448	268			do			do	16
343	Hall & Russell	do	A-7	1903	Bored, 12-inch	640	550	195			do			do	15
344	Dodge, Sinclair & Co	do	A-7	1899	Dug, 4 by 5 foot.	655	595	78			do			do	10

345	W. A. Norton	do	B-7		Bored, 7-inch	740	655	145			Wind			Domestic	
346	W. Llewellyn	do	A-7		Dug, 4 by 5 foot	655	557	102			Gas			Irrigation	10
347	Independent Water Co.	do	A-7	1902	Dug, 4 by 5 foot, 60 feet; bored, 12-inch, 287 feet.	665	565	347			do	1,000.00	1,200.00	Domestic; irrigation.	22
349	Charles Moser	do	A-8		Dug, 75 feet; bored, 10-inch.	520	445				do			Irrigation	
350	John Ungerland	do	A-9	1901	Dug, 4 by 4 foot.	540	500	60			do			Domestic; irrigation.	
351	Tropico Water Co	do	A-8	1897	Bored, 12-inch	535	439	150			do	400.00	2,500.00	do	70
352	George M. Payne	Los Angeles city	A-11	1902	do	340	331	50			do	89.00	1,000.00	Irrigation	20
353	C. E. Thom	San Rafael	B-5	1903	Dug, 6 by 6 foot	950	913	49			do	490.00		Not completed	
354	do	do	A-7		Dug, 6 by 7 foot	700	660	60			do			Domestic; irrigation.	15
355	do	do	A-7		Dug, 5 by 6 foot	700	660	100			do			do	10
356	Brooks Bros	Los Angeles city	A-12	1904	Bored, 12-inch	335	327	109			Not installed				
357	L. M. Sifford	do	B-12	1898	Dug, 3 by 3 foot	340	322	18	47		Wind			Not used	
358	Sarah Brown	do	B-12	1892	Dug, 3½ by 4 foot	340	307	35	48	68	do			do	
359	Los Angeles Stone and Sewer Pipe Co.	do	B-12	1903	Dug, 5 by 8 foot.	345	312	45			Steam			Manufacturing	
360	L. D. Drake	do	B-13		Bored, 6-inch	345	312	60?			Wind			Domestic	
361	Joe Cuceia	do	B-13	1895	Bored, 2-inch	300	287	22			do			do	
362	Mrs. M. S. Helm	do	B-13	1890?	Dug, 3 by 3 foot.	300	283	18	80	66	do			Not used	
363	Peter Capro	do	B-13	1897	Dug, 3 foot diameter.	285	276	9	64	66	do			Domestic	
364	Los Angeles Brewing Co.	do	B-13		Bored, 7-inch (2 wells).	290	280	57?	38	68	Steam			Brewery	45
364a	do	do	B-13		Bored, 12-inch (2 wells).	290	280	60?	38	68	do			do	
365	Mrs. J. E. Kennedy	do	C-13	1894?	Bored, 7-inch	315	273	98	96		Wind			Domestic	
366	L. M. Gilman	do	C-13		do	350	294	100+			do			Not used	
367	A. T. Leonard	do	C-13	1890?	do	340	295	153	74		do			Domestic	
368	Jessie P. Monte	do	C-14	1890?	Dug, 2½-foot diameter.	300	289	22	140		do			do	
369	J. G. Bell	do	C-15		Dug, 3-foot diameter.	340	276	71	91	68	do			Not used	
370	Diamond Hill Floral Co.	do	B-15	1892?	Dug, 5-foot diameter.	325	275	91	47		do			do	
371	J. C. Putnam	do	B-16	1895?	Bored, 7-inch	310	Dry.	98			do			No water	
372	Charles Karstadt	do	A-16	1894?	Bored, 6-inch	225	115?	125	45		do			Domestic	
373	J. Eustace	do	A-16	1896	Bored, 7-inch	240	188?	93	51		do			do	
374	Pacific Electric Rwy. Co.	do	A-15		Bored, 12-inch (3 wells).	245	159	100+			Not installed				
375	Inman Poulson Lumber Co.	do	A-17		Bored, 12-inch	225	150	165			do				
376	J. J. Maxey	Sec. 9, T. 2 S., R. 13 W.	A-17	1885	Bored	215	141		50		Wind			Domestic; stock	
377	L. Hooper	do	A-17	1874	Bored, 7-inch	215	167	50	44		do			Domestic	
378	Miss J. R. Dorsey	do	A-17	1901	Bored, 12-inch	210	140	211	53	65	Gas			Irrigation	†65
379	Miss M. J. Cameron	do	A-17	1899?	Bored, 7-inch	200	126	90?	49		Wind			Domestic	
381	Mrs. R. J. Withers	Sec. 10, T. 2 S., R. 13 W.	A-17	1902	Bored, 9-inch	195	135	206	43		do			Domestic; irrigation.	

Wells in the foothill belt of southern California—Continued.

PASADENA QUADRANGLE—Continued.

No. of well.	Owner.	Location.	Map location.	Year completed.	Class of well.	Elevation of surface (feet)—approximate only.	Elevation of water (feet).	Depth of well (feet).	Solids per 100,000.	Temperature of water (°F.).	Method of lift.	Cost of well.	Cost of machinery.	Use of water.	Quantity of water (miner's inches).
382	W. S. Holland	San Antonio	B-17	1902	Bored, 10-inch	195	125	155	50		Wind			Domestic	
383	Moore Bros	do	B-17	1902	Bored, 12-inch	190	119?	226		60	Compressed air			Irrigation	†100
383a	do	do	B-17	1904	do	190	119?	287			do			do	
384	Peter Scott	Sec. 10, T. 2 S., R. 13 W.	B-17	1900?	Bored, 7-inch	195	130	75?	48		Wind			Domestic	
385	J. W. Kniffin	do	B-17	1902	Bored, 10-inch	205	137	215	64		Gas, wind			Domestic; stock	
386	Hercules Oil Refining Co.	San Antonio	B-17	1902	Bored, 9-inch	205	145	280	40	60	Compressed air			Manufacturing	
387	W. M. Stephens	do	B-17	1905	Bored, 7-inch	210	142	175	43		Wind			Stock	
388	David Vaccero	Sec. 9, T. 2 S., R. 13 W.	A-17	1902	do	210	141	100	53		do	$100.00	$35.00	Domestic	
389	James Sweet	Sec. 10, T. 2 S., R. 13 W.	A-17	1901	do	200	133	104	53		do			Domestic; irrigation	
390	C. Smith	San Antonio	B-17	1902	do	190	129	100			do			Domestic	
391	J. H. Van Nest	do	B-17	1900	Dug, 62 feet; bored, 10-inch, 127 feet.	190	125	189	42	62	Steam	450.00	1,500.00	Irrigation	40
392	J. L. Graham	do	B-17	1899	Dug, 5 by 5 foot, 49 feet; bored, 12-inch, 151 feet.	185	125	200	43	61	Gas			do	†30
393	A. Koppe	do	B-17	1903	Dug, 5 by 5 foot, 65 feet; bored, 12-inch, 30 feet.	195	144	95	49		do		1,850.00	do	40
394	Lada Terry	do	B-17		Bored, 12-inch	195	136	110	46		Wind			Stock	
395	Mrs. Anderson	do	C-17	1879?	Bored, 7-inch	190	135	85	53	62	do			Domestic; stock	
396	A. A. Gast	do	C-17		do	185	125	100	47		do			Domestic	
397	J. G. Evans	do	B-17	1900	Dug, 6 by 6 foot, 40 feet; bored, 12-inch, 116 feet.	185	127	156	41	62	Gas			Irrigation	†15
398	do	do	B-17	1901	Bored, 12-inch	185	127	202	40	61	do			do	†15
399	L. A. Turner	do	C-17		Bored, 7-inch	175	130				Electric motor			do	
400	B. Beone	do	C-17	1900	do	185	138	98	47		Wind				
401	Chong Wong & Co.	do	C-17		do	185	145	63	51	62	do			Domestic; irrigation.	
402	E. C. Greening	do	D-17		Bored	175			27	68	Electric motor			Irrigation	†75
403	J. D. Hart	Los Angeles city	C-16	1901	Bored, 7-inch	210		100	53		Wind			Domestic	
404	Mr. MacHaley	do	B-16	1900	do	220	160	88	44		Gas			Domestic; stock	†1

405	Mr. Appel	do	B-17		do	220	160	93	46		Wind			do	
406	P. T. Sullivan	do	C-16	1882	Bored, 9-inch	240	148	140			do			Domestic	
407	J. O. Sullivan	do	G-16	1904	Bored, 10-inch	215		229			Not installed				
408	J. J. Adams	do	C-16	1899	Bored, 7-inch	215	157	150	38		Wind			Domestic; stock	
409	George E. Platt	San Antonio	D-16	1899	Bored, 12-inch	220	151	214	37		Gas			Irrigation	†70
409a	do	do	B-16	1902	Bored, 16-inch	220	151	218	37		do			do	
410	B'nai B'rith cemetery.	do	E-16	1902	Bored, 14-inch	200	150	200			Electric motor			do	†8
411	Laguna Land and Water Co.	do	H-17	1902	Bored, 12-inch	190	148	450	34		do			do	†200
412	J. H. Barbour	do	H-17	1903	Bored, 7-inch	200	151	130	31		Gas	100.00	300.00	Domestic; stock	
413	G. W. Scott	Paso de Bartolo	I-17	1904	Bored, 12-inch (2 wells).	160	150	107	23	64	do	500.00	1,500.00	Irrigation	†200
414	Louis Farmer	Potrero de Felipe Lugo.	L-15		Bored, 7-inch	225	216	20	20	62	Wind			Domestic	
415	F. F. Pellissier	La Puente	M-15		Bored, 12-inch	260	248		29		Gas			Irrigation	
416	John Waggoner	Paso de Bartolo	L-17	1900	Bored, 4-inch	235	218	48			Wind			Domestic; stock; irrigation.	†200
417	Rincon Irrigation Co.	do	L-16	1900	Bored, 10-inch	235	219	160	24	70	Gas			Irrigation	†110
418	J. D. Durfee	Potrero de Felipe Lugo.	L-15	1892	Bored, 7-inch	240	232	50	20	60	Wind			Domestic	
420	P. Cartota	San Rafael	A-11	1904	Bored, 12-inch	345	327	120			Gas			Irrigation	
421	J. N. Witham	do	A-8	1902	Bored, 9½-inch	545	435	170			do	350.00	650.00	do	
422	E. M. Ross	do	B-6	1897	Bored, 12-inch	805	797	119			do			do	†12
423	L. G. Allen	La Canada	A-3	1894	Dug, 5 by 5 foot	1,200	1,164	43			do			do	†8
424	A. C. Palfrey	San Rafael	B-4		Dug	1,225	1,033	214			do			do	†12
425	N. B. Huff	do	A-8	1904	Dug, 4 by 5 foot, 80 feet; bored, 9-inch, 110 feet.	515	435?	191			do			do	
426	Mr. Laux	do	C-8	1901	Bored, 12-inch	650	605?	200			do			do	†5
427	Mrs. Mary Hunter	Los Angeles city	C-12		Dug, 4 by 4 foot	390	358	34	35		Wind			Domestic; irrigation.	
428	Mrs. E. M. Winston	San Rafael	C-11	1903	Bored, 7-inch	505	461	85	25		do			Domestic	
429	Charles Wenrich	do	D-10	1899	Dug, 5 by 5 foot	575	563	40	40		do			do	
430	M. H. Dunn	do	C-9	1902?	Dug, 4 by 4 foot; bored, 7-inch.	580	564	150	21		do			Domestic; irrigation.	
431	J. W. Means	do	C-10	1896?	Dug, 4-foot diameter.	572	521	55	52		do			Domestic	
432	Pasadena Lake Vineyard Land and Water Co.	San Pasqual	F-6	1896	Dug, 6 by 10 foot; bored, 12-inch.	930	744	700	18		Steam	13,632.00		Domestic; irrigation.	
433	Pasadena Lake Vineyard Land and Water Co. and Pasadena Land and Water Co.	do	E-5	1899	Dug, 6 by 8 foot	1,000	975	55	23	64	Gas			do	25
434	do	do	E-5	1903?	Dug, 175 feet; bored, 200 feet.	1,140	965?	375	20	63	Compressed air		152.80	do	154
434a	do	do	E-5	1903?	Dug, 175 feet; bored, 400 feet.	1,140	965?	575	20	63	do				

Wells in the foothill belt of southern California—Continued.

PASADENA QUADRANGLE—Continued.

No. of well.	Owner.	Location.	Map location.	Year completed.	Class of well.	Elevation of surface (feet—approximate only).	Elevation of water (feet).	Depth of well (feet).	Solids per 100,000.	Temperature of water (°F.).	Method of lift.	Cost of well.	Cost of machinery.	Use of water.	Quantity of water (Miner's inches).
435	North Pasadena Land and Water Co.	San Pasqual	E-5	1893?	Dug, 4 by 8 foot.	1,125	980	160	21	65	Steam	[a]$20,145.00		Domestic; irrigation.	†30
436	Lincoln Avenue Water Co.	do	E, F-4		Dug, 5 by 7 foot, 236 feet; bored, 10-inch, 256 feet	1,200	955	492	25	65	do			do	†25
437	North Pasadena Land and Water Co.	do	E-6		Dug, 6 by 9 foot 110 feet; bored, 14-inch, 30 feet.	1,040	960	140	22	67	do	([b])		do	†50
438	H. E. Huntington	Santa Anita	I-8	1903	Bored, 10-inch	730	615	300			Electric motor			do	†18
439	Lloyd & Wood	do	L, M-7	1900	Dug, 4 by 6 foot	650	543	122	23		Gas			Irrigation	†12
440	E. J. Baldwin	do	K-9		Bored	505		300			do			do	
441	A. Scott Chapman	do	J-8	1892	Bored, 7-inch	660	620	450	24		Steam			do	†30
442	A. B. Chapman	do	J-8			630	617		19		Gas			do	
443	do	do	J-8	1898	Bored, 10-inch	610	606	560	18		do			do	150
444	do	do	J-9		Bored, 7-inch	606	606	156	19	71	Artesian			do	†4
445	do	do	J-8		Bored, 10-inch	615		400			Electric motor			do	†70
446	A. S. Chapman	do	J, K-8			600					Gas				†25
447	G. P. Wegener	Sec. 16, T. 1 S., R. 12 W.	G-12	1903	Bored, 10-inch	475	250	330	21		do			Domestic; irrigation.	†15
448	Pasadena Land and Water Co.	San Pasqual	G-9	1904	Bored, 12-inch	760	721?	215	23		Steam			Domestic	†80
448a	do	do	G-9	1904	do	760	721?	254	23		do			do	
448b	do	do	G-9	1904	do	760	721	256	23		do			do	
449	Graves & Bream	do	G-9	1904	Bored, 10-inch (3 wells).	765	725?	250-700			Flow into tunnel.			Irrigation	†60
449a	do	do	G-9		Bored, 10-inch (6 wells).	765	725?	250-700			do			do	
450	H. C. Allen	do	G-9	1891	Bored, 10-inch	755		130	27	71	Gas			do	2
451	Alhambra Addition Land and Water Co.	do	G-9	1896?	Bored, 6-inch (6 wells).	700	675	120	23		Compressed air			do	†100
452	Huntington Land and Improvement Co.	Sec. 3, T. 1 S., R. 12 W.	G-9	1901	Bored, 10-inch	600	588	417	22		Electric motor			Domestic; irrigation.	†68

453	do	Sec. 35, T. 1 N., R. 12 W.	I-9		Dug, 4 by 6 foot.	610	590		17	69	do			Irrigation	20
454	do	do	I-9	1904	Dug, 7-foot diameter; bored, 14-inch.	635	602	400			do			do	†100
455	A. E. Johnson	Potrero Grande	J-13	1899	Bored, 8-inch	260	258	430	20		Gas			do	66
456	Mr. McCloud	Sec. 13, T. 1 S., R. 12 W.	I-12	1904	Bored, 10-inch	335	274?	300	27		do			do	†30
457	Warde Bros	do	J-12	1904	do	340	280	375			do			do	†125
458	T. P. Herbert	Sec. 20, T. 1 S., R. 11 W.	L-13	1904	Bored, 12-inch	260	249	302	17	68	do			do	†60
459	G. Kallmeyer	San Francisquito	M-12	1904	do	300	267	127	22		do			do	†40
460	G. R. Green	do	M-11	1902	do	310	270	130	21	64	do			do	†155
461	Frank Proctor	do	M-12	1901	Bored	315	265	140			do			do	†100
462	C. H. Rhodes	San Rafael	G-9	1904	Dug, 5 by 5 foot, 50 feet; bored, 10-inch, 85 feet.	740		135			Steam			do	
463	Frank Jones	Santa Anita	J-8	1903	Bored, 12-inch	650	618	236			Compressed air			do	18
464	Jack Butler	do	J-8	1904	Bored, 10-inch	645	619	198			Gas			do	†30
465	Sunny Slope Water Co.	do	J-9	1903	do	610	605?	380			Electric motor			do	
466	Pasadena Land and Water Co.	San Pasqual	E-7	1901	Dug, 6 by 8 foot.	775		75			Gas, steam			Domestic	†85
467	S. Richardson	do	G-10	1898	Bored, 8-inch (2 wells); 12-inch (2 wells).	650	580	150–180			Steam			Irrigation	†75
468	East Pasadena Land and Water Co.	do	G-8	1902?	Dug, 6 by 8 foot, 90 feet; bored, 12-inch (4 wells)	785	715	630–734			do			Not used	†100
469	Marengo Water Co	do	F-9	1901	Bored, 12-inch (3 wells).						Gas, electric motor (2 plants).			Irrigation	†120
470	George S. Patton	do	G-9			725					Gas			do	
471	do	Santa Anita	H-9		Dug, 40 feet	675	660	300–400			Electric motor			do	†100
472	Huntington Land and Improvement Co.	do	H, I-9			650	612	200			do			Domestic; irrigation.	†7
473	Pasadena Land and Water Co.	San Pasqual	E-9		Dug, 6 by 8 foot	750	710	70			do			do	
474	J. T. Eldridge	do	I-8		Bored, 7-inch	650	607	140			Gas			do	
475	Titus ranch	do	J-9		do	620	608	132			Not raised			Not used	
476	G. B. Renfro	Sec. 18, T. 1 S., R. 11 W.	K-12		do	300	279	46			Wind			Domestic	
477	Mr. Beck	San Francisquito	L-12		do	275	260				do			do	
478	M. Ritter	do	L-13		do	275	257	60			Hand			do	
479	Mrs. McClure	Sec. 21, T. 1 S., R. 11 W.	L-13		do	265	251	61			Wind			do	
480	E. J. Baldwin	Santa Anita	K-8		Bored, 12-inch	535	535	500			Artesian, gas			Irrigation	†75

[a] Including No. 437.

[b] Including No. 435.

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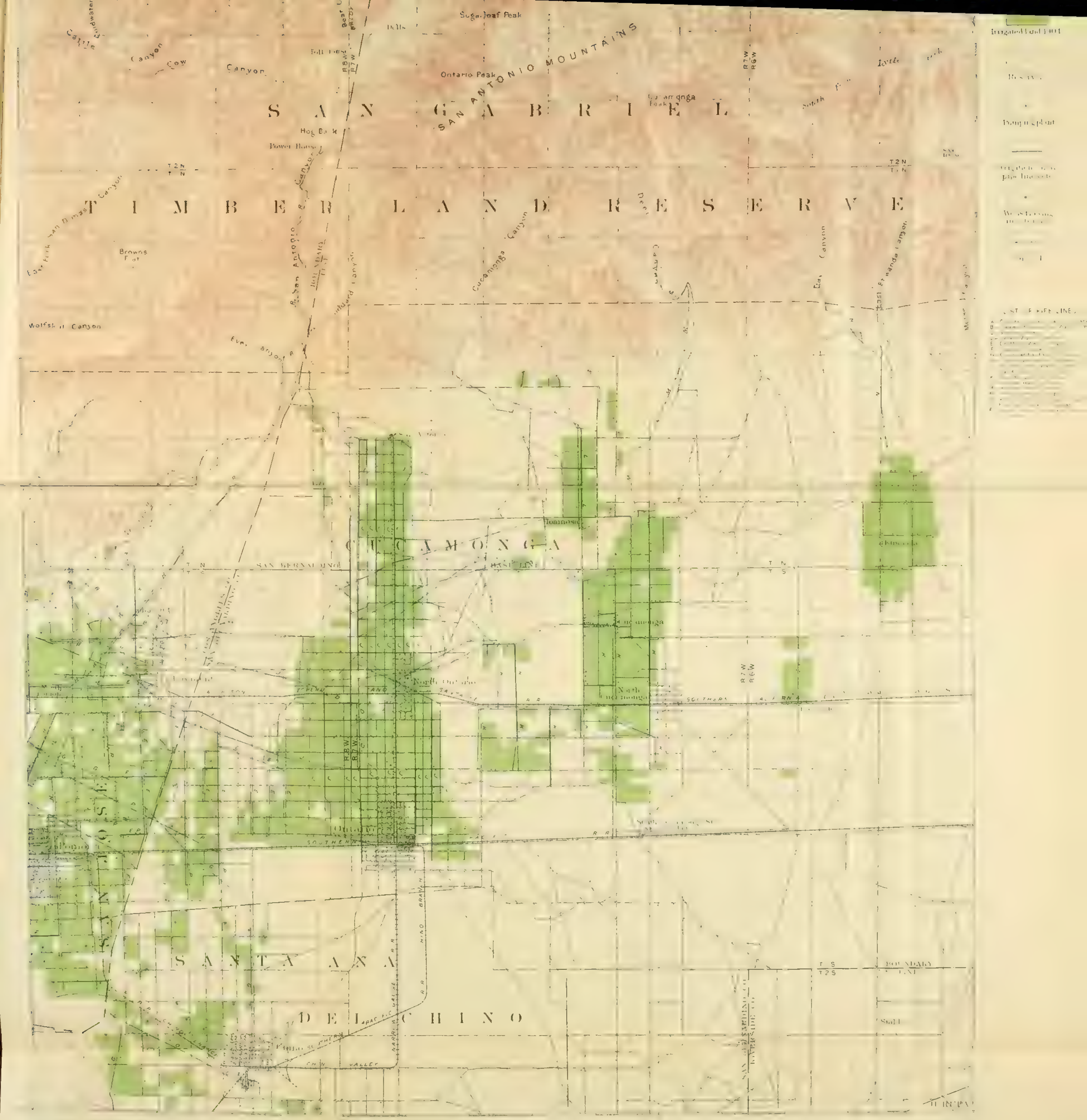
MAP SHOWING THE ARTESIAN AREAS AND HYDROGRAPHIC CONTOURS IN THE VALLEY OF SOUTHERN CALIFORNIA

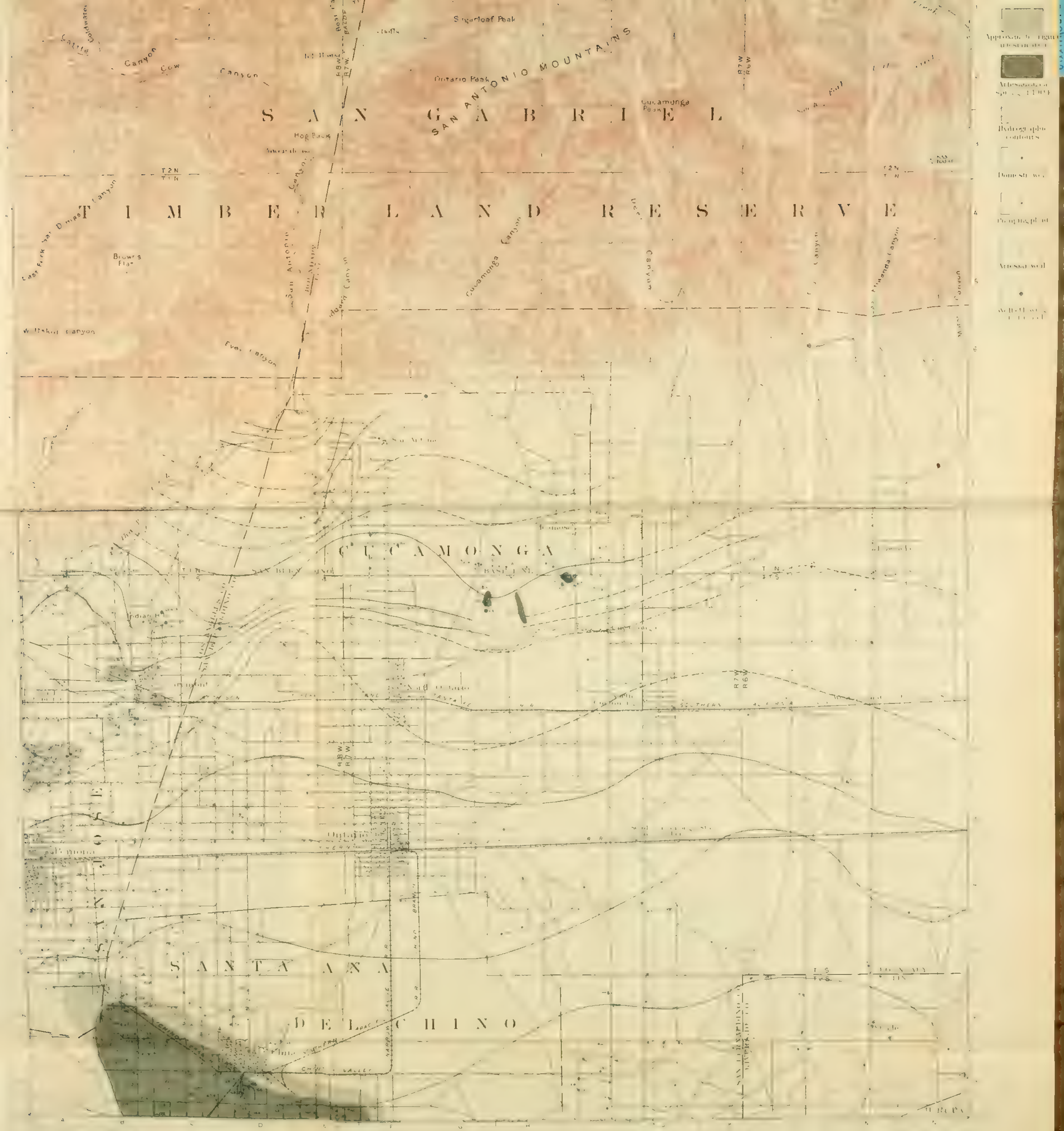
DATA COMPILED BY W. C. MENDENHALL, 1901



MAP SHOWING IRRIGATED LANDS, CANALS, PIPE LINES, AND PUMPING PLANTS
IN THE CUCAMONGA QUADRANGLE, CALIFORNIA

DATA COMPILED UNDER THE DIRECTION OF W. C. MENDENHALL, 1904 AND 1905

1907



MAP SHOWING WELLS, ARTESIAN AREAS, AND WATER LEVELS
IN THE CUCAMONGA QUADRANGLE, CALIFORNIA

DATA COMPILED UNDER THE DIRECTION OF W. C. MENDENHALL, 1904 AND 1905

MAP SHOWING IRRIGATED LANDS, CANALS, PIPE LINES, AND PUMPING PLANTS
IN THE POMONA QUADRANGLE, CALIFORNIA

DATA COMPILED UNDER THE DIRECTION OF W. C. MENDENHALL 1904 AND 1905

MAP SHOWING WELLS, ARTESIAN AREAS, AND WATER LEVELS
IN THE POMONA QUADRANGLE, CALIFORNIA

DATA COMPILED UNDER THE DIRECTION OF W. C. MENDENHALL 1904 AND 1905

1907

MAP SHOWING IRRIGATED LANDS, CANALS, PIPE LINES, AND PUMPING PLANTS
IN THE PASADENA QUADRANGLE, CALIFORNIA
DATA COMPILED UNDER THE DIRECTION OF W. C. MENDENHALL, 1904 AND 1905

MAP SHOWING WELLS, ARTESIAN AREAS, AND WATER LEVELS
IN THE PASADENA QUADRANGLE, CALIFORNIA

DATA COMPILED UNDER THE DIRECTION OF W. C. MENDENHALL, 1904 AND 1905

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

WATER-SUPPLY PAPER 220

GEOLOGY AND WATER RESOURCES

OF

A PORTION OF SOUTH-CENTRAL OREGON

BY

GERALD A. WARING

WASHINGTON
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1908

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INDEX MAP SHOWING LOCATION OF AREA DISCUSSED

1
46°
45°
44°
43°
42°
41°

GEOLOGY AND WATER RESOURCES OF A PORTION OF SOUTH-CENTRAL OREGON.

By Gerald A. Waring.

INTRODUCTION.

OBJECTS OF RECONNAISSANCE.

The rapidly increasing settlement and development of the West which has accompanied the recent industrial expansion of the United States has led to a growth of interest in all of those factors that affect its adaptability to human needs. One of the clearest evidences of this increasing interest is the constant demand for definite and trustworthy information concerning its climate, soils, mineral resources, timber, and water. So great is this demand that the Federal and local bodies which have been organized to study the natural resources are scarcely able to meet it.

In the arid and semiarid sections no question is of more vital importance than that of water supply. Where water can be introduced or developed in abundance colonization will take place; where water exists in limited quantity, sparse settlement is possible; but where water is not to be had present conditions must continue. The water-resources branch of the United States Geological Survey has for many years been making systematic studies of water supplies, both surface and subsurface, and in connection with work under way in many localities, both in the East and in the West, in the fall of 1906 the writer was assigned to carry out a reconnaissance in south-central Oregon.

AREA EXAMINED.

The area examined lies mostly within and includes the greater part of Lake County, so that in the following pages it will often be referred to simply as Lake County. Its location and extent are shown on the index map, Pl. I.

The field work was done, except along the main roads, almost entirely on horseback, for nearly all of the country except the steeper

mountain slopes may be thus traversed. Since much of it is sparsely settled, a light buckboard, on which food, blankets, and horse feed could be carried, was used wherever practicable along the rather widely separated roads.

As no map showing the relief with any approach to accuracy existed, the accompanying topographic map (Pl. II) has been prepared; it is based on field observations with pocket compass and aneroid barometer and on data compiled from all other available sources. Samples of soil and water were also collected for analysis, and rock specimens were gathered for future study. The following report on this region therefore includes a discussion of its present water resources and the development of a greater supply, a statement of its agricultural possibilities, and a summary of the data collected concerning its geology.

ACKNOWLEDGMENTS.

In collecting these data the writer gained much information from the residents of the county, to whom acknowledgment is here made for aid rendered in various ways, both during and since the time spent in the region. Thanks are due especially to Mr. F. P. Light, of Lakeview; Mr. Virgil Conn, of Paisley, and Mr. F. M. Chrisman, of Silver Lake.

PREVIOUS STUDY.

This region has been little studied by geologists or other scientists, partly because, being remote from railroads, it is difficult of access, but mainly, perhaps, because of the monotony of its natural features and its sparse settlement. In 1882 Prof. I. C. Russell made a hasty trip through the region, his observations being embodied in the Fourth Annual Report of the United States Geological Survey.[a] The late Thomas Condon, professor of geology in the University of Oregon, crossed Christmas Lake Valley, and Prof. Edward D. Cope also visited the region and published some results of his studies on its fishes and fossils.[b] Mr. J. O. Snyder, professor of zoology at Stanford University, has been studying the fishes of its lakes and streams, and the results of his investigations will appear soon in a bulletin of the Bureau of Fisheries; but with the exception of the papers of Professors Russell and Cope, little has been published treating especially of this area. Professor Russell probably visited and studied a greater extent of this northwestern country than any other scientific observer, and many references to his various publications will be made in this paper.

[a] Russell, I. C., A geological reconnaissance in southern Oregon: Fourth Ann. Rept. U. S. Geol. Survey, 1884, pp. 431-464.

[b] Cope, E. D., The Silver Lake of Oregon, and its region: Am. Naturalist, November, 1889, pp. 970-982; On the fishes of the Recent and Pliocene lakes of the western part of the Great Basin and of the Idaho Pliocene lake: Proc. Philadelphia Acad. Sci., vol. 35, 1884, pp. 134-167.

GEOGRAPHY.

GENERAL FEATURES.

Central and southeastern Oregon lies in the northern end of that great area between the Rocky Mountains and the Sierra Nevada from which no streams discharge into the ocean, and which on this account is known as the Great Basin region of interior drainage.

Lake County is in the northwestern extension of this Great Basin region. To the north, beyond the Pauline Mountains, is the John Day River basin, and to the northwest, beyond the Walker Mountains and other eastern outliers of the Cascade Range, is the valley of Deschutes River; while the Summer Lake "rim rock," known as Winter Ridge, and its mountainous southward extension separate the area herein considered from the Klamath Lake drainage area.

Although this southwestern portion of the county is mountainous, the surface of the northern part and of the region to the east is that of a broken plateau, whose mean elevation above sea level is between 4,500 and 5,000 feet. Over this uneven surface the many depressions either contain shallow lakes or are sinks in which temporary ponds exist only during the wet season. In this plateau region there are no rivers, and even well-defined stream channels are rare.

TOPOGRAPHY.

MOUNTAINS.

The area just referred to, in the southwestern part of the county, is cut into more mountainous relief by the branches of Chewaucan and Sprague rivers, giving it a very different kind of topography from that of the rest of the area considered, in which absence of the type of relief produced by stream erosion is a chief characteristic. On the southeastern border of the Chewaucan River drainage basin an elevation of more than 7,000 feet is reached at several points, while other, more isolated masses, such as Crooks Peak, rise to heights of more than 6,500 feet. The steep mountain slopes back of Lakeview also rise fully 2,000 feet above the valley, and contain two or three summits well above the 7,000-foot contour.

SCARPS.

Although the northern and eastern part of the area studied has the character of a broken plateau, one may travel in some directions for many miles in the level sandy lake valleys or over the approximately level rocky "high desert" without crossing more than an occasional depression. But the chief features that relieve the monotony of the region are the great scarps that have given it the broken character. These trend generally north and south, and the

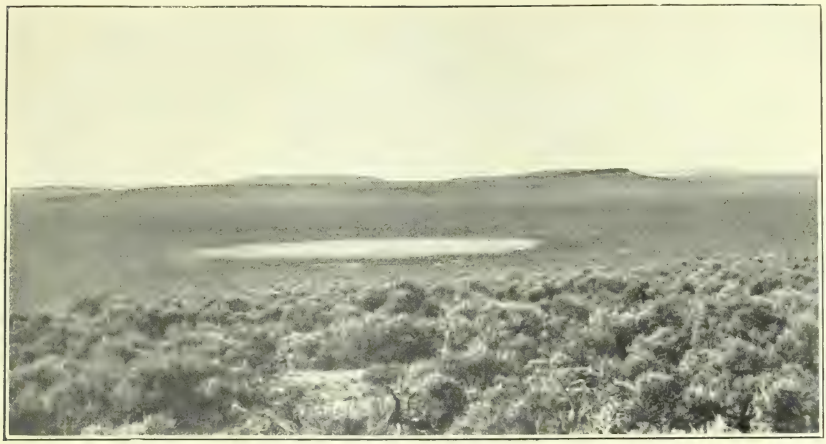
four principal lines border the principal lake valleys, or undrained basins. Along its entire eastern side Warner Valley is thus bounded by a great escarpment, rising to a height of approximately 3,000 feet above the valley floor, while on its western side a lower but also very abrupt scarp limits this valley. Another very prominent line of bluffs marks the eastern edges of the basins of Goose, Abert, and Alkali lakes. Steep but comparatively smooth and rounded slopes mark this escarpment where it forms the western face of the hills above Lakeview and overlooking Goose Lake, but along the edge of Abert Lake it forms a very striking cliff that rises from the water's edge to a height of fully 2,000 feet, the upper 600 feet being nearly perpendicular. The hills north of Lake Abert obscure this feature for a few miles, but along the Alkali Lake basin there is again an abrupt scarp, 1,200 feet in height, which is lower to the north and dies out near the base of Wagontire Mountain. Another scarp, which forms a low bluff near the south end of Lake Abert, extends along the northeast side of Chewaucan Marsh, attains a height of about 1,300 feet opposite Paisley, and passes into the broken country beyond. Although on the western side of this marsh also the hills rise steeply, it is along Summer Lake that the fourth prominent scarp line is best developed, in the ridge named by Frémont "Winter Ridge." Silver Lake is confined on each side by scarps which at its southern end reach 400 feet in height, but these are only a few miles in extent, and are by no means as conspicuous as the others described.

MINOR FEATURES.

The surface of the rocky plateau area lying between Christmas Lake and Alkali Lake valleys, known as the "high desert," has a minor relief peculiar to itself. Instead of well-defined stream channels, it has a series of long depressions, approximately parallel, trending in a general way from north to south. The larger of these resemble on a small scale the coulées of Washington, described by Calkins;[a] they are often limited by nearly vertical walls of basalt approximately 50 feet in height. The bottoms of these depressions are so nearly horizontal as to make it in some instances impossible to tell with the eye alone the direction of the slope. In them a string of sinks or small playas takes the place of a drainage channel. One of these sinks, near the road between Alkali Lake and Paisley, is shown in Pl. III, A. In the spring they may contain a few inches of water, but during the greater part of the year they are dry.

As for other minor features in the northern part of the county, mention may be made of the several mountain masses and peaks

[a] Calkins Frank C., Geology and water resources of a portion of east-central Washington: Water-Supply Paper No. 118, U. S. Geol. Survey, 1905, p. 42.



A. TYPICAL SINK IN HIGH DESERT NEAR ALKALI LAKE.

B. HILLOCKS NEAR ALKALI LAKE.

C. ALKALINE POOLS IN CHRISTMAS LAKE VALLEY.

that rise above the common level, such as Wagontire and Juniper mountains, and the smaller, isolated mesas and buttes.

In this part of the county, just north of Christmas Lake Valley, there is an area covered with lava and cinder cones representing a very recent period of volcanic activity. Many of these cones or extinct volcanoes are very perfect funnel-shaped craters, and rise directly from the nearly level, though in detail harsh and jagged, surfaces of the lava flows.

The sand dunes near Fossil Lake, in Christmas Lake Valley, illustrate still another topographic type. Extending eastward from this lake, which is only a few acres in extent, is a region of sand hills, fully 6 miles long and averaging perhaps 2 miles in width. The prevailing west wind has heaped the sand into great dunes with steep eastern faces and gentle westward slope. These are slowly traveling eastward and have encroached nearly 3 miles on the part of the "high desert" known as Pine Ridge.

The lower slopes along the western side of Summer Lake are examples of typical landslide topography, and were noted by Russell in 1882. Their principal features are the small basins between the back of the slide and the cliff from which the mass has been loosened, in which water sometimes collects, and the great blocks of tuffaceous material in the landslide débris, whose bedding planes dip in various directions.

Another similar landslide area is that at the southern end of Lake Abert, at the base of the escarpment. It is illustrated in Pl. IV.

Still another minor but interesting feature is to be seen typically developed in the flat near Alkali Lake. Conical hillocks, in many cases 10 feet high, somewhat resembling great haycocks (Pl. III, *B*), and usually topped by greasewood, are thickly clustered on the level surface. Along the borders of the flat these are worn down and rounded off into the more usual "hogwallow" type of mound.

These minor features help much to relieve the monotony of the surface, and, as they are on this account very noticeable, have been thought worthy of brief mention; but the three most significant general features in the topography of this region, and the ones that should be borne in mind in considering the land forms are (1) the great persistent scarps that extend from north to south, (2) the undrained basins at the bases of these scarps, usually occupied by lakes or playas, and (3) the general lack of well-defined drainage over a large part of the surface.

LAKES.

The county has been well named, for besides the larger lakes, Silver, Summer, and Abert, approximately 15, 70, and 60 square miles in area respectively, the Warner Valley chain of lakes and the northern part of Goose Lake lie within the county. Thorn, Christmas, and

Fossil lakes are small water bodies in Christmas Lake Valley, and there are also several large marshes and numerous playas or intermittent lakes. But these numerous water bodies must not be taken to indicate an abundance of water in the region, for it will be remembered that none escapes through surface streams, and that the lakes are only the collecting basins for the run-off from the mountain slopes or the flow from the springs. In a well-watered area with the topographic peculiarities of Lake County the water bodies would be much more numerous and much larger than those that exist there.

CHARACTER OF THE LAKES.

All of the lakes are shallow. None are known to exceed 25 feet in depth, although there is an unconfirmed report of greater depths in the eastern side of Lake Abert. Christmas and Fossil lakes are only 2 or 3 feet deep, while Alkali Lake is really a playa, since during the summer and fall months it is only an alkaline flat containing two or three briny pools.

The size of these shallow water bodies is dependent on the seasonal rainfall, as, indeed, is their very existence. Since the settlement of the country several important changes in their outlines have taken place. During the earlier emigrant days the trail crossed Goose Lake Valley farther south than at present, the place now being under several feet of water. In the early days of Lakeview (now about 6 miles from the lake) the name of the town was not a misnomer, for the lake then extended much farther north than at present, and in 1869 it overflowed for a short time southward into Pit River. In 1881 also it is said to have overflowed for two hours during a severe gale from the north.[a] Warner Lake has shrunk during the last half century. The present litigation over lands in its valley hinges on the question whether between 4,000 and 5,000 acres, now dry, was swamp land or part of the bed of the lake at the time of the passage of the swamp land act in 1860. Although before his reconnaissance in 1882 Silver Lake was not known to have gone dry, Russell inferred from its comparative freshness that it must have done so within recent years, since lakes having no outlet are believed to be freshened by desiccation. Therefore the fact that after the exceptionally dry season of 1887–88 the lake did dry up, its bed was taken up for farms, and one season's crops were gathered before the lake again filled, is of especial interest.

ALKALINITY.

Like all lakes having no outlet, those of the area under discussion are alkaline, the waters of Summer and Abert lakes being exception-

[a] Russell, I. C., A geological reconnaissance in southern Oregon: Fourth Ann. Rept. U. S. Geol. Survey, 1884, pp. 446-457.

SCARP AND LANDSLIDE AREA NEAR SOUTH END OF LAKE ABERT.

ally so. Russell, in his reconnaissance report,[a] gives an analysis of water from Lake Abert, by F. W. Taylor, and remarks that the percentage of potassium salts is greater than in any other lake whose composition is known. But the following analysis of water from this lake is given by T. M. Chatard,[b] who says:

The sample was collected by H. T. Biddle at the middle of the west side of the lake, 1 foot below the surface, 30 to 40 feet from shore, September, 1887. * * * This analysis shows, as would be expected, that the water of Abert Lake does not differ materially from that of any other alkali lake so far discovered. Its low percentage of sulphate is its greatest merit [for soda extraction] since it is of all impurities the most difficult to remove and the most deleterious when present.

Analysis of water of Lake Abert.[a]

[Average of two samples. T. M. Chatard, analyst.]

	Grams per liter.	Per cent.
SiO_2	0.232	0.59
K	.538	1.37
Na	14.690	37.51
SO_3	.588	1.50
O	.118	.30
CO_2	7.024	17.93
O	2.462	6.28
Cl	13.462	34.67
H	.058	.15
	39.172	100.00
HYPOTHETICAL COMPOSITION.		
SiO_2	.232	.59
KCl	1.027	2.62
NaCl	21.380	54.58
Na_2SO_4	1.050	2.68
Na_2CO_3	10.611	27.09
$NaHCO_3$	4.872	12.44
	39.172	100.00

[a] Chatard says of this analysis (in Am. Jour. Sci., 3d. ser., vol. 136, 1888, pp. 146–150): "The total quantity at my disposal was about 200 c. c., an amount too small for any extended research, but sufficient for all practical purposes. For each determination 25 c. c. (=25.7792 grams) were taken. Specific gravity, 1.03117 at 19.8°."

This analysis, giving a content of about 3.9 per cent of salts, shows the water to be more strongly impregnated than ocean water, which contains about 3½ per cent of mineral salts.

No analysis of the water of Summer Lake is at hand, but a test at its western edge, with the electrolytic bridge,[c] indicates a content

[a] Op. cit., p. 454.

[b] Chatard, T. M., Natural soda, its occurrence and utilization: Bull. U. S. Geol. Survey No. 60, 1890, pp. 50–52.

[c] The alkaline salts of natural waters are electrolytes, and the more alkaline a water is the less resistance it offers to the passage of an electric current. Hence by means of an electrolytic bridge, consisting essentially of an electric battery, resistance coils, and a suitable cup to hold the water to be tested, the resistance offered to the passage of the current can be measured, and by comparison of this with the resistance measurements of other waters of which analyses also are available the amount of salts in solution can be roughly determined. Waters containing only 8 or 10 parts of salts in 100,000 are exceptionally pure, and those containing 30 parts in 100,000 are considered very good. The limit for domestic or irrigation purposes is about 400 parts in 100,000, although it depends largely on the character of the salt content.

The average alkaline content of the fresh lakes of North America is given by Russell (Lakes of North America, p. 55), as between 15 and 18 parts in 100,000.

near the shore of 500 or more parts of salts in 100,000. A sample of the efflorescent alkali from its eastern shore consisted almost wholly of the sulphate of soda (Glauber's salt), carbonate of soda (sal soda), and bicarbonate of soda (baking soda).

Similar tests of the waters of Silver and Thorn lakes indicated only about half as great a salt content as the water of Summer Lake. At its northern end Christmas Lake is very alkaline, but at its southern end, where the water is of much better quality, it is fed by an intermittent spring. The efflorescence here, as at Summer Lake, consists of the carbonates and sulphate of soda.

CLIMATE.

GENERAL CONDITIONS.

The climate of eastern Oregon is very different from that of the better known western valleys of Willamette and Columbia rivers, for east of the Cascade Range precipitation is scanty and the region is largely desert in character. The climate is not severe, however. Its temperature has been compared to that of Ohio or Illinois, although its precipitation is much less. The summer days are warm, often excessively so on the rocky plateaus, but the nights are cool, and in some parts of the country frost may be expected in any month of the year. The stormy season is late, February, March, and April often being the most disagreeable months, while open weather sometimes lasts in the fall until Christmas time. On the higher mountains and plateaus snow may lie all winter, but in many of the valleys it melts after each storm.

Weather records have been kept in only two places in Lake County for any length of time—at Lakeview and at Silver Lake. A station was established at Paisley two years ago, and it is hoped that records will also soon be kept at Cliff, near Fossil Lake. In a late bulletin of the Department of Agriculture[a] the following statements, especially applicable to Lake County, are made in an article on the climate of Oregon by Edward A. Beals. He says that the seasonal precipitation is chiefly between the months of October and March, with a secondary maximum during May and June, followed by a relatively dry summer. The prevailing winds are southerly in winter and from the northwest in summer, southerly winds being at all times the rain bringers, and in summer causing the lowest temperature. The hot winds are from the northeast in summer, while in winter the cold winds are from this quarter. Thunderstorms occur in spring and early summer, but rarely during the winter months.

[a] Henry, A. J., Climatology of the United States: Bull. Q, U. S. Dept. of Agriculture, 1906, pp. 498–499.

TEMPERATURE AND RAINFALL RECORDS.

In the tables following are compiled the data obtainable on temperature and precipitation in this region:

Average temperatures and precipitation at Silver Lake and Lakeview, Oreg.[a]

Month.	Silver Lake (elevation, 4,300 feet).		Lakeview (elevation, 5,000 feet).	
	Mean temperature in °F.	Mean precipitation in inches.	Mean temperature in °F.	Mean precipitation in inches.
December	30	1.2	30	2.2
January	29	.8	28	2.4
February	30	1.0	29	2.2
Winter	30	3.0	29	6.8
March	36	1.0	36	1.7
April	43	.9	43	1.4
May	50	1.2	51	1.7
Spring	43	3.1	43	4.8
June	56	.8	58	1.2
July	62	.6	66	.3
August	62	.2	66	.3
Summer	60	1.6	63	1.8
September	53	.5	57	.7
October	45	1.1	49	.9
November	36	1.1	38	2.0
Fall	45	2.7	48	3.6
Annual	44	10.4 [b] 10.06	46	17.0 [b] 16.73
Mean maximum	61		60	
Mean minimum	28		32	
Absolute maximum	104 July, 1891		102 July, 1896	
Absolute minimum	-32 Nov., 1896		—24 Jan., 1888	

[a] From Bull. Q, U. S. Dept. Agr., 1906, pp. 966, 969.
[b] From First Bienn. Rept., Oregon State Engineer, 1905-6, Pl. I.

Rainfall record at Silver Lake, Oreg.[a]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1889											1.48	1.31	
1890	1.03	2.74	1.04	0.34								Tr.	
1891	.62	3.08	.77	1.46	2.65	2.24	1.63				1.50	1.46	
1892	.12	.91	2.40	.77	2.52								
1893	1.50	.75	1.09	.93									
1894						.82							
1895				1.89	.64	.30	.13	0.39	0.18	0.49	2.32		
1896													
1897	.25		.80	.25	1.91	2.65	.07	.00	.39	.23	.13	1.47	
1898	.27	.30	.15	.22	1.87	.76	.20	.05	.20	.56	2.03	.38	6.99
1899	1.40	.24	2.57	1.02	.49	Tr.	.00	.40	.37	1.44	.75	1.68	10.36
1900	.80	Tr.	.31	.53	.90	.42	Tr.	.45	.49	2.09	.40	.95	7.34
1901	.08	1.69	.30	.10	.34	.04			1.09	1.31	.57		
1902	.24	1.45	.25	2.27	.67	Tr.						2.16	
1903	1.73	.55	1.15		.52	.72							
1904				.98	.65	.54	1.60	.00		.56	.55		
1905			1.03	.70	1.48	2.33	.05	.00	1.34	.55	.23	.07	(?) 7.78
1906	1.98	.55	1.89	.38	2.18	1.08	.64	.78			.42	1.68	11.58

[a] Station established by Signal Service October, 1889. No instrument shelter used for first few years Temperature record therefore considered somewhat unreliable, but rainfall thought to be good.

Rainfall record at Lakeview, Oreg.[a]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1890						0.23	0.00	Tr.	2.29	0.12	Tr.	1.00	.....
1891	0.49	4.95	2.06	1.09	3.09	2.97	.90	0.15	.38	.42	1.07	6.38	24.55
1892	2.01	1.57	1.27	2.18	2.04	.67	.08	Tr.	1.51	1.99	3.78	2.47	19.57
1893	1.80	2.07	1.74	2.44		.07	.31	.00	1.19	1.59	3.68	1.65	17.51
1894	4.00	4.92	3.18	.58	2.24	.....	.....	.....	.....	.....	.97	3.45	.....
1895	5.45	1.02	2.00	.52	1.33	Tr.	.20	.45	.60	Tr.	1.16	2.25	14.62
1896	3.55	1.00	2.32	3.94	2.21	.10	.50	.51	1.17	.60	2.96	1.45	20.31
1897	1.13	2.95	3.13	1.03	.92	2.09	.10	.10	.86	.36	1.78	1.68	16.13
1898	1.40	1.08	.10	.05	1.74	.24	.08	.....	Tr.	.95	1.25	1.50	.....
1899		.80	2.25	1.18	1.10	.20	Tr.	.50	.00	2.60	2.15	2.43	.....
1900	1.44	1.71	1.04	1.38	.....	.....	.....	.....	.....	.....	.....	1.03	.....
1901	3.01	2.58	.59	1.07	.69	Tr.	.00	.27	1.09	1.29	1.73	2.78	15.10
1902	.83	3.32	1.41	2.28	2.22	.10	.45	.18	.21	1.17	2.20	2.38	16.75
1903	3.39	1.14	1.93	.48	.53	1.23	.46	.32	.06	.44	4.94	.99	16.11
1904	1.41	5.45	4.53	2.76	.27	.59	.43	.03	1.10	1.43	.20	3.27	21.47
1905	1.67	.73	2.47	.44	1.41	.70	.00	.07	.50	.22	.63	1.08	9.92
1906	4.63	1.59	3.14	.53	1.88	1.21	.20	.00	.82	.....	1.52	3.72	19.24

[a] Station established by Signal Service January 1, 1884; discontinued October 13, 1888. Reestablished as voluntary station by Signal Service June 1, 1890.

These records, besides showing the much greater precipitation at the southern station, indicate that at Lakeview the climate is also slightly warmer. Although the mean maxima and minima of temperature do not indicate as great extremes in the southern part, the mean seasonal temperatures show that there really is a greater average difference between summer and winter at Lakeview than in the more open Silver Lake region. The difference in these records is probably due more to the difference in elevation of the two observing stations, than to any other single factor. The station at Lakeview is at about 5,000 feet elevation, or 700 feet higher than that at Silver Lake. The former place is also at the base of a range of steep mountains, while the latter is in the open valley.

VEGETATION.

There are few absolutely barren areas in southern Oregon, such as are found in northwestern Nevada and in the Mohave and Colorado deserts. Nearly all of the country produces some sort of natural growth, though in no place is this so dense as to interfere seriously with travel on horseback or on foot. The mountains are rather openly forested with several varieties of pine and fir and with a scattering undergrowth of manzanita, buckthorn, and mountain mahogany. The lack of dense underbrush has no doubt in large measure protected these forests from fires such as yearly burn along the western slopes of the Cascades. The rocky plateaus support a scanty growth of sage and are in some places dotted with junipers, which seem to grow best on the most rocky areas. The growth of pine trees at Pine Ridge, on the eastern side of Christmas Lake Valley, among the dead trunks of junipers, is a unique occurrence in this region, and seems closely related to the soil conditions and moisture as affected by the drifting sands from the valley.

In the sandy alluvial soil of the lake valleys the sage often grows to large size. Three species of rayless goldenrod are also found, chiefly in the valleys and on the borders of playas. On the more alkaline flats, as at Christmas Lake and Alkali Lake, the greasewood seems to thrive best, its young shoots being one of the earliest sources of forage for stock in the spring.

Over nearly all of this area, both in the mountains and on the plateaus, bunch grass and rye grass grow in sufficient quantity to furnish range for thousands of head of stock, while from the marshes many tons of wild hay are cut every year for winter feed.

A number of the native plants were incidentally collected during the study of the region, and were afterward kindly identified by Mr. Le Roy Abrams, assistant professor of systematic botany at Stanford University. Among them are a dozen species of grasses and of desert shrubs, the black sage (*Artemisia tridentata*), common juniper, rayless goldenrod (*Bigelovia*), greasewood (*Sarcobatus*), lupine, and milk vetch or loco weed. In the lake valleys, the marsh elder, bush willow, and buckwheat, with other small plants, were found. On the mountain slopes, besides the forest trees of pine and tamarack, are the buckthorn, manzanita, maple, cottonwood, and quaking asp, together with a number of shrubs and plants of the rose family, among which are the mountain mahogany, cherry, strawberry, and wild plum. The wild plum is found in abundance in several localities. The fruit ripens in September, when it is eagerly gathered by both the Indians and the settlers.

The common horehound and alfilerilla, with one or two other California plants, were noticed along the more traveled roads and around sheep corrals, and have probably been introduced from the south by immigrants and flocks of sheep.

ANIMAL LIFE.

In the late seventies the last mountain sheep were seen in this region. Although deer and antelope have been abundant until recent years, the latter rarely came down into the valleys, and the deer also are now seen mostly in the higher country, as the lower lands are being fenced. The gopher, woodchuck, and hedgehog are found especially in the cultivated sections, and the coyote and rabbit in nearly all parts. Around the lakes ducks, geese, and various other kinds of waterfowl abound, while a few sage hens may be occasionally flushed on the plains. But several varieties of chipmunk seem to be the most common form of wild life, both in the timbered areas and on the plains. The scarcity of birds and other small forms of wild life over much of this region is noticeable.

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SETTLEMENTS.

Within the county, comprising 7,834 square miles,[a] with a population close to 3,000, there are four towns. Lakeview, the county seat (Pl. V), has a population of about 1,000; Paisley, 300; New Pine Creek, 200, and Silver Lake perhaps 100.

Mail and stage lines, operated six times a week, connect Lakeview with New Pine Creek and Madeline (Cal.) to the south, Bly and Klamath Falls to the west, and Paisley, Summer Lake post-office, and Silver Lake to the north. To the east there is service with Plush, Adel, and Warner Lake post-offices three times a week. Egli post-office, just within Harney County, has communication twice a week with Riley and Burns to the northeast. In the newly settled Christmas Lake Valley provisional post-offices have been established at Lake and Cliff, with weekly service to Silver Lake.

The nearest railroads are at Madeline (narrow gage), 95 miles south of Lakeview; Weed (Cal.), and Pokegama (Oreg.), each about 135 miles west of Lakeview; and Shaniko, 166 miles (according to the post-route map) northward from Silver Lake. The latter place indeed claims to be farther from a railroad than any other post-office in the United States. A railway route has recently been surveyed through Christmas Lake Valley, however, and it is hoped that work will soon be begun on the line and that Silver Lake will not hold this unique distinction very much longer.

Except near Lakeview the county roads do not receive much care, and in consequence travel over those least used is slow.

The freight rate between Shaniko and Silver Lake, by teams, is 1½ cents a pound; so that prices of all heavy or bulky supplies that have to be shipped in, especially grain, flour, and potatoes, are high.

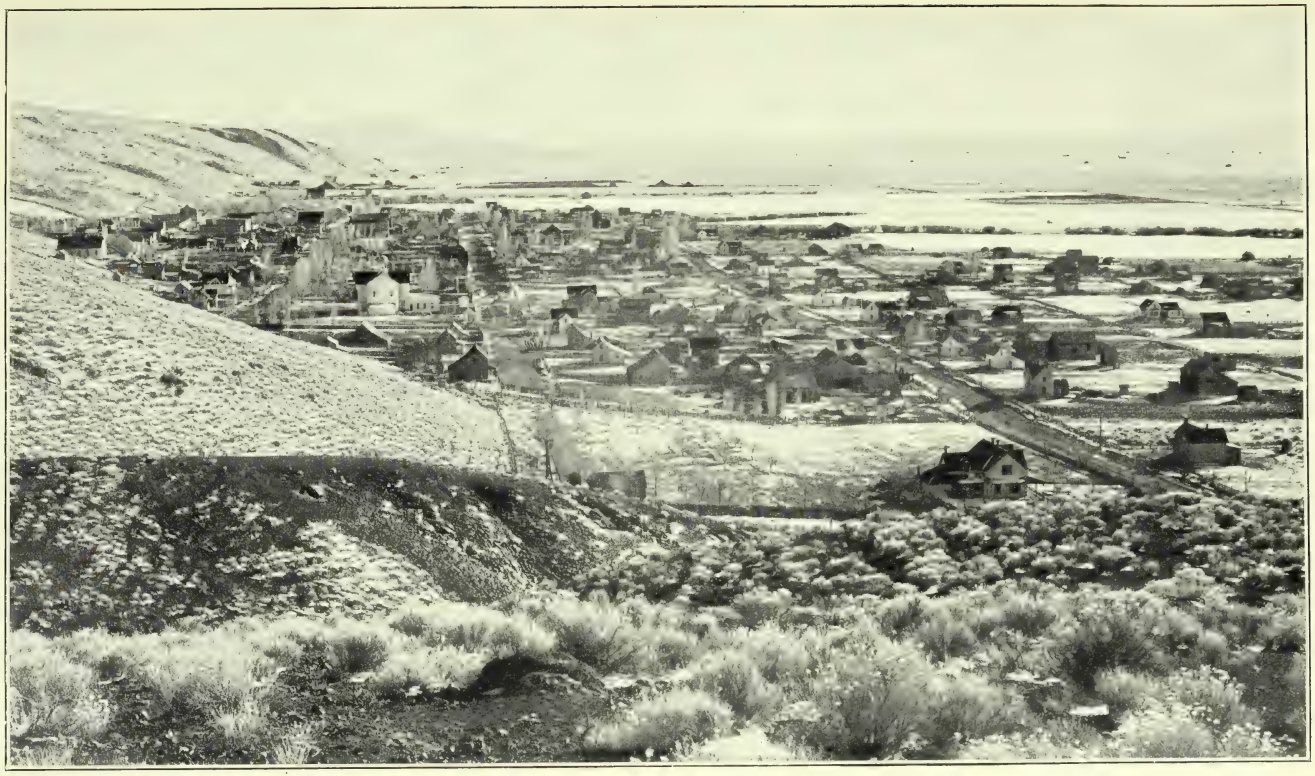
Telephone lines connect the settlements with the railway points, and several cooperative lines connect most of the isolated ranches. Quick communication may thus be had throughout much of the county. In other matters, too, the people are progressive. Lakeview has a water system supplied by springs in the mountains above the town, and both it and New Pine Creek have electric lights, while several buildings in Silver Lake are also furnished with electric light from the plant of Mr. F. M. Chrisman, which uses power generated by a distillate engine.

INDUSTRIES.

GRAZING.

On account of the presence of natural forage grasses and the unfitness of much of the country for any other purpose stock raising has become the chief industry. Horses and cattle roam in great numbers

[a] Gannett, Henry, The forests of Oregon: Prof. Paper U. S. Geol. Survey No. 4, 1902, p. 25.



LAKEVIEW, OREG., FROM THE NORTH.

over the plateaus or "high desert," and are owned chiefly by the interests that control the hay ranches of the marsh lands. The scarcity of summer limits the range of cattle during that period to the mountains or, on the desert, to the vicinity of water holes. They are usually rounded up for feeding on the marshes during the severe weather of the early spring months. Horses, being able to travel more rapidly, can range farther from water than cattle, and often become so wild that it is almost impossible to collect them for branding or for market. It is said that a band now roams the lava beds in the northern part of the county, and that determined efforts for several years have failed to capture them, because of their wildness and the rough character of the lava surface.

Sheep also constitute an important factor in the county's wealth. During the summer months the flocks are kept in the mountains, where water can be obtained, and are not brought down into the valleys until November or December, when sufficient snow has fallen to furnish water during the winter.

AGRICULTURE.

Comparatively little farming has yet been done, although most of the fruits and vegetables consumed in the county are raised along the eastern side of Goose Lake and the western shore of Summer Lake. Apples and potatoes are the staples, but the farms near New Pine Creek are also noted for their melons. Nearly all garden vegetables can be obtained during the summer and early fall months, in spite of the fact that frosts are likely to kill the more tender plants. It is the general opinion that more extensive cultivation is lessening the tendency to early frosts, and it is claimed that vegetables, such as tomatoes, can now be grown in several places in the county where formerly they could not.

A number of small dairies, sufficient to supply the local demand for milk and butter, are established in Summer Lake and Goose Lake valleys, but little or none of their products are shipped out.

At Paisley and on the western side of Summer Lake, where water for irrigation is obtained, there are several alfalfa fields, and in these localities a few fields of barley and rye are also grown.

LUMBERING.

Three or four small sawmills supply the local demand for lumber, the price at the mill being about $12 a thousand feet board measure. Yellow pine furnishes nearly all the timber, and also supplies fuel for heating and other purposes, as there is no coal in the region. Gannett[a] estimates the stand of merchantable timber in Lake County as

[a] Gannett, Henry, The forests of Oregon. Prof. Paper U. S. Geol. Survey No. 4, 1902, p. 10.

3,106,000 feet board measure, all of which is yellow pine, the average stand to the acre being 3,000 feet.

MINING.

Near New Pine Creek there has recently been some gold-mining excitement, but in a district a little south of the State boundary. The only prospects worthy of mention within Lake County are those of the Coyote Hills, in what is known as the Lost Cabin gold mining district. This district was brought to the notice of mining men in August, 1906, by the Loftus brothers. The value and extent of the deposits have not yet been proved. Such values as have been found are in oxidized ores in andesitic breccias, a mass of these more acid rocks beneath the basalts that are so generally distributed over Lake County forming the boss exposed in the Coyote Hills.

The alkaline flat at the southeast end of Summer Lake has been located for soda, and a part of Alkali Lake as borax claims, but no development work has been done in either locality.

A small quantity of saltpeter (nitrate of potash) of high quality has been found on the northwestern side of Wagontire Mountain, but the character and extent of the deposit are not known.

HISTORICAL NOTES.

Some historical notes on the county have been assembled in a "History of Central Oregon,"[a] and the following extracts may not be out of place here:

As early as 1838 a form of government was exercised by the Methodist Missions in "Oregon," and two years later a petition for a civil government was sent to Congress by the people settled on Puget Sound and in the tide-water region of Columbia River. In 1838 Col. J. J. Abert prepared a map showing Warner Lake and other natural features of the eastern country, from data procured by trappers and explorers of the Hudson Bay Company, but Col. John C. Frémont seems to have been the first to cross the area now Lake County, and to bring out a clear account of the region. He left The Dalles in November, 1843, on the return trip of his exploring expedition, traveling southward to Klamath Marsh, then eastward across Sycan Marsh. Here the explorers were overtaken by a heavy snowstorm, and when they suddenly came to the edge of the cliff overlooking Summer Lake and saw the valley below green and inviting they bestowed the name of Winter Ridge on the bluff and its present name on the lake at the foot of the bluff. After traveling past Chewaucan Marsh and Lake Abert, which Frémont named after Col. J. J. Abert, chief of the Corps of Topographical Engineers, under whose instructions he was working,

[a] An illustrated history of Central Oregon, compiled by F. A. Shaver, Arthur P. Rose, and R. F. Steck. Western Hist. Pub. Co., Spokane, Wash., 1905.

they reached Warner Valley on December 23, and spent Christmas day on the edge of the lake, which they called Christmas Lake. Thence they traveled southward to Pyramid Lake and into California.

Nearly six years later, in 1849, Capt. William H. Warner, United States topographical engineer, explored the country north and east of Goose Lake for an emigrant trail from Sacramento, and was killed by Indians in the valley now bearing his name. It was not until the early sixties that the country was again penetrated by whites, when the discovery of gold in the John Day and Powder River regions led to the establishment of the military post of Fort Klamath along the route of travel from California and Nevada to the new mines. There was also a line of travel between Steins and Warner mountains, leading later to the establishment of Fort Warner. So, although without a settler, Lake County was traversed by a number of parties during these years.

In 1868, when as a result of General Crook's campaign the Shoshone Indian war ended, immigration began. In 1872 a weekly mail route was established between Ashland, Oreg., and Lake City, Cal., with a post-office at New Pine Creek. Four years later a post-office was established at Lakeview. In 1874–75 a post-office was established on the western side of Silver Lake, the town of Silver Lake not being founded until 1886. There were several settlers at Paisley in 1871, and seven years later a store was opened at that place. The county of Lake was formed in 1874. At first it included the present Klamath County, but did not contain Warner Valley, and it did not receive its present boundaries until 1886.

GEOLOGY.

CHARACTER AND AGE OF ROCKS.

In studying the geology of the region—the kinds of rocks and their structure—all of the consolidated materials that were seen are volcanic effusives and related volcanic muds, or tuffs. These rocks belong to several lithologic classes and to more than one geologic period, but by far the most extensive series is that of the basaltic flows. These cover nearly all of Lake County and extend eastward beyond Steins Mountain and northward beyond the John Day region, where fossils that have been collected from interbedded sedimentaries determine the age of the flows as Miocene.

No such fossil-bearing beds were found in the Lake County area, and the effusive material was not traced in detail to the place where such beds are exposed. But the material is so similar in lithologic character, in the amount of deformation it has undergone, and in its general relation to the Cascade Range to the west that there is little

hesitation in placing it in the same general series with the widely extended and well-known Miocene lavas of Washington and northern-central Oregon. Although these Miocene basaltic lavas cover nearly all of the region examined with the exception of the lake valleys, there are sufficiently large areas of lavas of other types to warrant a preliminary separation into three groups—older acidic effusives, older basaltic effusives, and recent eruptive material. These are tentatively mapped, with their approximate areas, so far as these could be determined in a rapid reconnaissance, on Pl. VI (in pocket).

CLASSES OF ROCKS.

OLDER ACIDIC EFFUSIVES.

The rocks of several mountain masses in this region differ enough from the more common basalts, both in the nature of the topography to which they give rise and in their petrologic character, to warrant us in considering them as belonging to an earlier period of more acidic effusion, when the lavas poured out were andesites, rhyolites, and related obsidians. They are perhaps of early Tertiary or pre-Tertiary age. In the succeeding effusions the materials were either basaltic or tuffaceous.

The Coyote Hills and Rabbit Hills masses are placed in the older class because they are composed largely of a light-colored glassy or porphyritic rock that seems to have been disturbed and eroded before being surrounded by the basaltic flows. These lavas are much more acid than the surrounding basalt, and they are regarded tentatively as rhyolites, andesites, and trachytes. In three other places—near Lakeview, near the head of Chewaucan River, and between Silver and Summer lakes—similar rocks were found. Slides of these were examined by E. S. Larsen, jr., and identified as andesite.

Gray Butte, Big Juniper Mountain, and Horning Bend are composed of light-colored rocks that appear also to have been disturbed and eroded before the outpouring of the later basalts. They are rhyolitic in character.

The general form of Wagontire Mountain and its relation to the basalts that dip westward away from it suggest that it also may have been produced by an earlier, possibly local effusion, uplifted since the outpouring of the basalt flood. On its westward side a glassy andesite was found, but the rocks of the eastern portion are more crystalline in texture and apparently more basic.

The black obsidian of the Glass Buttes, to the northwest, and of Horse Mountain, to the southwest, is probably related to the Wagontire Mountain mass.

OLDER BASALTIC EFFUSIVES.

Basalts.—The basalt of the main flows over the surface of the country is for the most part a dark-gray, fine-grained, rather vesicular rock, weathering on the more level areas into brown rounded cobbles and bowlders that make a very uneven surface, difficult to travel over.

On the higher peaks the more resistant types of this rock contain much iron and strongly affect the compass needle. Very little soil has formed over these high desert areas. Approximately parallel partings, usually at intervals of only a few feet, mark the division between successive flows, but in some places much thicker beds are exposed. Fissures nearly perpendicular to the parting planes break the basalt into blocks, which by transverse fracturing are reduced to smaller and smaller fragments, forming the characteristic talus slopes of the cliffs.

Tuffs.—In several places over the northern and western parts of the county there are remnants of a great tuffaceous flow or series of flows. This tuff underlies the upper flows of the basalt, but probably belongs to the same general period of effusion. Fort Rock (Pl. VII, *A*), an isolated mass in the northwestern part of Christmas Lake Valley, is the most prominent of these remnants. It is imperfectly crescent shaped, nearly one-third of a mile across, and rises in its highest part 325 feet above the valley floor, with perpendicular cliffs 200 feet above its talus slopes. The tuff of which it is composed is a tawny, rather firmly cemented material, consisting of fragments of effusive rocks and volcanic cinder. This material is largely used in the western part of the county for building purposes, being soft when first quarried and easily cut into blocks that harden on exposure, and as it is used especially for chimneys it is locally known as "chimney rock."

A thick tuff bed also exists in the mountains south of Paisley and is well exposed in the Chewaucan River canyon a short distance above the town. This tuff, which is colored various shades of red and blue, has been mineralized to some extent by quartz and calcite. Toward its southern end considerable prospecting for gold has been done, and good values are reported to have been found in some places. The remains of an old arrastre, half a mile below these workings show that for a number of years the locality has been prospected for the precious metal.

Interbedded with the basalts are thinner layers of tuff, or volcanic mud and ash. These are usually rather fine grained, white or red in color, and contain fragments of basaltic rocks. Where exposed along cliffs these tuff beds thin out, as if lenticular in shape, and in some instances serve to accentuate any unevenness in the associated basalt beds.

These tuffs also exhibit interesting contact phenomena, as at North Alkali Valley, where a white tuff bed about 4 feet thick is exposed for several miles in the cliff along the eastern side of the valley. The contact with the underlying basalt is sharp and exhibits no alteration. From this line upward the color changes evenly through brown to black at the upper contact, where the tuff has been melted to a beady glass by the heat of the succeeding flow. This overlying rock is lighter colored and less dense than the usual basalt, and covers much of the area surrounding Alkali Lake basin, but it probably belongs to the same period of effusion as the more close-textured basalt to the south, into which it seems to grade.

RECENT ERUPTIVE MATERIAL.

In the northern part of the county is an area covered by sheets of lava and small volcanic cones or craters that represent a very recent period of volcanic eruption. Black vesicular basaltic rock constitutes the main part of the flow, while the cones are built up of slaglike fragments of scoria and volcanic bombs. This material clearly was ejected at a period much later than that of the great Miocene flows. It is probably Pleistocene in age.

VALLEY FILLINGS.

The loose Pleistocene filling of the valleys and the alluvial material brought down by streams may be considered as a fourth class of surface material in this region.

Lake deposits.—No marine beds were seen, but some lake deposits should be mentioned here. Along the hills east of Summer Lake, and fully 150 feet above its present level, there are beds aggregating 25 feet or more in thickness. These are composed of basaltic pebbles and shells of fresh-water mollusks, cemented into a conglomerate by lime carbonate.

Many of the stones around the borders of the lake basins are coated with a hard, white deposit of lime, in many cases half an inch thick. One mass of this material 10 or 15 feet in diameter, observed on the western edge of Summer Lake, is probably a tufa deposit of lime carbonate, such as Russell found so common along the shores of the ancient Lake Lahontan, in Nevada and California.

In all of the lake valleys there are deposits of silts, sands, and clays that form the floor of the valley and usually bury any coarser material that may be in the basin. Remains of Pleistocene mammals fix the age of these deposits at Fossil Lake, in Christmas Lake Valley, where somewhat extensive collections have been made by representatives of the Smithsonian Institution, and in 1904 by a party from the University of California.

Alluvium.—Some alluvium is to be found where the several streams debouch into the open valleys, but in few places is the area thus covered of great extent. Probably at the mouth of the Chewaucan River canyon there is the largest area of this stream-deposited material. Here the gravel-covered terraces at Paisley have clearly been built by the river, probably as a delta in the former lake, and the low divide between Summer Lake and Chewaucan Marsh is largely if not entirely formed of river wash.

Honey Creek, in Warner Valley, has also brought down and deposited on the valley edge a large amount of gravel.

Landslides and the slower weathering action that produces talus have also brought down much loose material from all the cliffs and steep slopes, but the areas covered by such material are not large.

Although in comparison with the great rocky basaltic areas these loose materials are geologically of minor importance, it is from them that practically all of the limited quantity of ground water now used is obtained. Hence from the view point of the present water resources in the region this fourth class of unconsolidated material is perhaps the most important. The cultivable land is also limited to these areas of lake and stream deposits, so that the possible agricultural portions of the county—neglecting alkaline conditions, which will be discussed in detail later—are shown on the geological map (Pl. VI) by the colors that represent these deposits.

STRUCTURE.

FAULTS.

Probably in but few other places in the world is the geologic structure so well exhibited in the present land forms as it is in southeastern Oregon. Here the main features of relief are a direct result of deformation of the rocks. This deformation has resulted in faults, which are the main structural features, as their expressions in scarps are the main topographic features.

In most of the Great Basin region the typical Basin Range structure, produced by the faulting and tilting of long, narrow orographic blocks, is largely obscured by erosion or by earlier complex structures. But in Lake County erosion has acted very little on these great blocks, and little or no deformation preceded the faulting, so that the typical structure is evident in the present conformation of the surface. The geologic cross section (see Pl. X) through Chewaucan Marsh, Lake Abert, and Warner Valley well exhibits this characteristic tilted block structure, and in Pl. VIII, reproduced from Russell's "Reconnaissance," the block between the marsh and Lake Abert is seen to be of this origin.

[a] Russell, I. C., Geological reconnaissance in southern Oregon: Fourth Ann. Rept. U. S. Geol. Survey, 1884.

In a general way the southern country is more broken by faults than the northern. This fact is not as evident from the map (Pl. II) accompanying this report as it would be were more of the region to the east and north shown; still, it will be noticed that in the northern part of the area mapped prominent scarps are not in evidence, while they are in the southern portion.

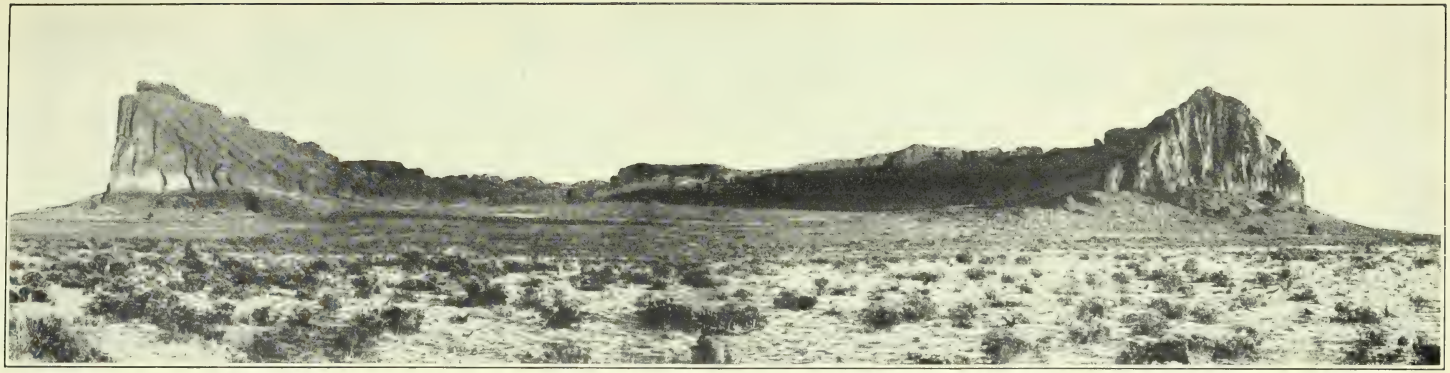
FOLDS.

Besides these tilted blocks there are low folds in the bedded lavas. In the production of these, however, the rock itself has been bent little if any. The very slight opening and closing of the multitude of approximately vertical fractures in the beds has been sufficient to allow the low folds to be formed. In Lake County the other structural features seem closely related to a great upward fold or anticline of this character, which has been extensively faulted in places; and the structure of the region has been tentatively worked out on this assumption, as follows:

The axis of this major anticline extends from Silver Lake southward through Goose Lake Valley, approximately along the straight line A–A′, Pl. VI. At its southern end the monoclinal slope at the western side of Goose Lake Valley and the steep slope at its eastern side suggest that here the anticline has broken down and that Goose Lake Valley lies, as it were, on the dropped keystone of an arch. (See section, Pl. X.) To the north dips in the beds indicate that Chewaucan River has cut its channel along the axis of the fold for a number of miles. Through Summer Lake Valley it appears that the anticline has again broken down, its western side remaining in place to form Winter Ridge, while the eastern is buried beneath the lake deposits. White Rock, a tuffaceous exposure in the bluff at the northwest side of the valley, seems closely to mark the northern point of this breaking down, for northward from it a very evident plunging anticline forms the slopes to Silver Lake. In the hills north of this lake the fold does not show.

The near parallelism of Elder Creek with the axis A–A′ is also to be noted, and in a broader way the approximate parallelism of Chewaucan Marsh.

One of the areas examined in which the folds are irregular and complex in a minor way is that at the northern end of Summer Lake Valley. As indicated on the geologic map (Pl. VI), the dips of the beds on each side of Sheep Lick Draw show that a smaller fold, whose axis is B–B′, exists here, which dies out toward the crest of the divide between Christmas Lake and Summer Lake valleys. This divide has the character of a cross anticline whose axis is C–C′, and these three upward folds, together with the synclinal fold up whose trough



A. FORT ROCK, FROM THE SOUTHEAST.

B. ALKALI LAKE FROM THE NORTH.

the county road between Summer Lake and Silver Lake passes, have produced a peculiarly warped surface.

In the southeastern part of the area studied the plateau between Goose Lake and Warner Lake valleys has the character of a wide, low syncline, while the dips on each side of southern Warner Valley indicate that, like Goose Lake Valley, it has been formed by the faulting of an anticline, as shown in the section through south Warner Valley (Pl. X). At its northern end the dips indicate more purely monoclinal faulting, as shown in the section through Chewaucan Marsh (Pl. X).

Over all of the northeastern part of the county the beds lie approximately horizontal, indicating, as before stated, that there has been less deformation in that region. Even at a short distance from the base of Wagontire Mountain the surface beds are nearly level.

There are many minor scarps, especially in the broken country northeast of Summer Lake and at the south end of Silver Lake. These, however, do not seem to be of fault origin, but are apparently weathering rather than structural features.

As in the topography the scarps were shown to be the main features, so the faults producing these scarps and their associated undrained basins are again emphasized as being the chief structural features. In this respect the low folds are treated as of secondary importance; for although, as tentatively shown, the structure has been determined largely by a great anticline which has collapsed in places, the most striking features along this fold are the results of faulting.

PHYSIOGRAPHY.

EARLY HISTORY.

In attempting to trace the development of the present topographic features of Lake County and vicinity it must first be considered at the period immediately following the outpouring of the great basaltic lava floods of Miocene time. Only the very scantiest and most fragmental evidence exists for deciphering the history of the region before this period, but data for unraveling the later evolution of the land forms are much more abundant.

At the close of the great lava outflow Lake County and the adjacent regions north and east probably formed one widely extended plateau, above which projected, like islands in the basaltic inundation, only isolated peaks of the former surface, such as Big Juniper and Little Juniper mountains, Gray Butte, and the Coyote Hills. There could have been little topographic diversity in the entire region, for the prominences mentioned were but minor elevations, widely scattered, and rising but little above the general broad levels.

Drainage could not have been definite or well developed; indeed, if precipitation was as light then as it is at present, there were probably few streams in existence.

DEFORMATION.

Some time after this broad constructional plateau came into existence, at a time which can not be fixed definitely on the basis of any evidence gathered within Lake County, but which, to judge from similar events whose history has been more closely traced farther to the north and to the south, was in the Pliocene epoch, earth movements began that resulted eventually in the uplifting of the Cascade Range in the north and of the Sierras in the south. Although the locus of these movements, or the line of their greatest intensity, lay well to the west of the area under discussion, this area was itself markedly affected by them. The movements, whose axis of greatest intensity coincided roughly with the present crest of the Cascade Range, exhibited as they passed eastward a constantly diminishing intensity, so that here, while great mountain ranges did not come into existence as one of their products, the old plateau, which had existed before the disturbance, was extensively modified. This modification in various parts of the piedmont area at the eastern base of the Cascades took the form in some localities of low folds and resulting ridges, in others of faults of limited throw with a resulting appropriate topography, and in still others of a combination of faults and folds. Whatever form the movement took, it produced a marked change in the preexisting land forms.

In Lake County faulting seems to have been the dominant expression of this movement, although folding also took place. The great scarps which are so characteristic of the region and which limit practically all of its major depressions on one or the other side date from this period and are themselves due directly to the breaking of the lava beds, their broken edges now constituting the scarps in question.

The preexisting plateau was broken by these movements into a series of irregular blocks, some of which were dropped bodily and are limited by faults on either side, while others are tilted to the east or the west, giving structures that, since the work of Gilbert and Russell, have come to be known as Basin Range structures. In other parts of the area, especially farther north, where the movements seem to have been less intense or less definitely localized, broad ridges were raised without fracturing. Such a ridge is that which extends north of east from the vicinity of Squaw Peak through St. Patricks Mountain. This ridge separates Silver and Summer lakes, where it is clearly anticlinal in character, but eastward from this area it gradually dies out or becomes less definite as a structural feature.

PRESERVATION OF DEFORMATIONAL FEATURES.

The topographic forms that resulted from this series of general crustal movements seem to have been preserved with comparatively little modification to the present day, and from this fact it appears that, though the region is one of light rainfall, so that the usual erosional forces operate with comparatively slight intensity, the movement must have been relatively recent. For had these forms existed for any extended time, even under desert conditions of minimum precipitation and minimum stream development, they would have been considerably modified. The greater scarps, like those which limit on the east the valleys in which lie Goose, Abert, and Alkali lakes, are comparatively unmodified. This is equally true of the scarps that confine the Warner Lakes on the east and of the somewhat less pronounced scarps that limit them on the west. Winter Ridge, to the west of Summer Lake, although it has been slightly modified by landslides since it came into existence, exhibits substantially its original form. The greatest evidence of the action of erosion or disintegration is found in a few localities like that at the south end of Silver Lake. Here exists a valley whose extension is occupied by Silver Lake, and scarps have been formed limiting this valley on both the east and the west that can not be accounted for as fault features, because Silver Lake and its valley seem to occupy the axis of an unbroken anticline. Rocks along its crest were presumably weakened and therefore easily subject to attack by disintegrating agents, and perhaps on this account these agents have been most effective here.

Over large areas in the northern part of the county, areas that are now known generally as the "high desert," the effect of the crustal movement that elsewhere produced the scarps and the valleys that accompany them seems to have been merely to warp slightly the original constructional plateau, so that it is now a high, rolling, irregular plain, changed scarcely at all from its original condition. Similarly the surfaces of some of the blocks whose edges form the conspicuous scarps—surfaces like that of the great ridge that separates Abert Lake and Warner Lake valleys—exhibit little change, other than the tilting they have suffered, from the original surface of the plateau from which they are derived. It is probable, indeed, that portions of these surfaces coincide with the surface that existed before deformation had affected the region at all. The faulting and folding, in other words, have deformed the surfaces as well as the rocks, and these deformed surfaces are the present topographic features of Lake and adjacent counties.

EROSIONAL MODIFICATIONS.

Where streams like Chewaucan River drain higher ridges in the western portion of the county—ridges that because of their great

height have a greater rainfall and consequently a greater run-off—gorges due to erosion have been formed, and other modifications of the original deformational surface are found. These modifications are usually greatest where the rocks were made more vulnerable to attack by erosional agents through weakening along fault lines or upturning along folds. At such places sharp canyons have developed that follow strike lines closely and have been cut out along weak zones in the disturbed rocks. But except near the western edge of the county, where these favoring conditions of high rainfall, sharp relief, and weakened rocks have combined to yield limited areas of topographic forms that are erosional instead of constructional, the surface of the county is almost exclusively dependent upon constructional forces.

LAKES.

Present lakes.—As an immediate result of the movements by which the ridges with their limiting escarpments and the valleys that lie at the bases of these escarpments were formed, the lakes that dot the surface of the county and give it its name came into existence at the lowest points of the deformed surface, from the accumulation there of such slight run-off as the meager rainfall of the region furnished. Each constructional basin has its own drainage, and the drainage accumulates at the lowest point within the basin. If it is more than sufficient to satisfy evaporation, a lake exists in the depression; if evaporation is as effective in removing the water as rainfall is in supplying it, playas or intermittent lakes, like Alkali Lake, result.

Quaternary lakes.—During Quaternary time the basins of Lake County contained much greater bodies of water than at present. These have left evidences of their former extent in the terraces or ancient shore lines cut in the surrounding hills, in the lake deposits, and, as at Paisley, in the formation of deltas rather than of alluvial fans opposite canyon mouths. At Willow Ranch, south of New Pine Creek, shells of fresh-water mollusks are said to be found 150 feet above the present lake surface. On the eastern side of Summer Lake Valley similar shells are found, and faint terraces along Chewaucan Marsh show that Lake Abert, the marsh, and Summer Lake were once continuous. According to Russell,[a] the water once stood 260 feet deep over the marsh and 300 feet deep in Summer Lake Valley. Silver Lake and Christmas Lake valleys once formed a wide, continuous, rather shallow expanse of water; but the present small bodies are not to be considered as remnants of this former lake.

The most distinct terraces in the region are to be found in the hills surrounding the Alkali Lake basin. Several deeply cut notches in these hills show successive stages of the lake level, the highest being

[a] Russell, I. C., A geological reconnaissance in southern Oregon: Fourth Ann. Rept. U. S. Geol. Survey, 1884, p. 439.

275 feet above the present flat. The approximate extent of these Quaternary lakes is indicated by the areas of alluvium shown on Pl. VI.

HYDROGRAPHY.

STREAMS.

From the nature of the topography of this region, the area draining into each lake basin is rather limited, and the amount and character of the discharge depend almost wholly on local precipitation.

ABERT LAKE DRAINAGE.

Chewaucan River and its branches above Paisley form the largest drainage system in the county, with an area of about 272 square miles. Nearly all of this is in the higher, timbered region, where conditions are favorable for heavier precipitation and for the conservation of the rainfall and snowfall, hence the stream flows in good volume throughout the year. Near Paisley its canyon opens rather abruptly into the lake valley, and after flowing beyond its former delta deposit the water, except where carried off through drainage canals, sinks in Chewaucan Marsh. At the lower end of the marsh the water again rises, and after dropping over a low basaltic ledge empties into Lake Abert.

Several other smaller streams east of the upper portion of the Chewaucan basin carry northward much water from the mountains and join Chewaucan River before it reaches Lake Abert. Moss, Coyote, and Crooked creeks are the largest of these. Moss Creek, with from 30 to 40 miner's inches summer flow, drains only a small area, but its source in springs in the timbered mountains insures it a fairly reliable discharge. Near its entrance into the lower Chewaucan Valley part of the water is diverted to irrigate alfalfa and vegetables. Coyote Creek flows through a small open valley in the portion of its course between the mountain slopes and the gorge that carries it toward Lake Abert, but during the late summer a great part of its water sinks before reaching Chewaucan River. Crooked Creek in its course through its upper valley has cut a channel in the alluvial filling 20 feet or more deep, with vertical banks, and in its lower stretches it is confined in a narrow canyon until it reaches the more open valley a few miles south of Lake Abert. It unites with Chewaucan River just before the latter enters the lake.

SILVER LAKE DRAINAGE.

The drainage basin of Silver Creek is also mostly a timbered area, the stream being fed mainly by waters from the slopes south and southwest of Hager Mountain. Together with Bridge Creek and

Bear Creek (locally known also as Buck Creek), two streams that drain the slopes farther to the west, it supplies Silver Lake. Like Chewaucan River, these streams sink in Pauline Marsh, and through it the water reaches Silver Lake.

SPRAGUE RIVER DRAINAGE.

The western edge of the county is drained either by Sprague River and its branches directly or through Sycan Marsh into this stream, whose waters finally discharge into Klamath Lake. This area is also mountainous and wooded, but drains westward, away from the region with which this paper is concerned.

GOOSE LAKE DRAINAGE.

A number of small streams flow into Goose Lake, the chief of these in Oregon being Drews and Cottonwood creeks. These have their sources in the wooded slopes of the northwestern side of the valley, but their waters generally sink in the lowlands before reaching the lake. Bullard Creek, near Lakeview, and Kelly Creek, near the town of New Pine Creek, are but small mountain streams, while in California a number of similar small intermittent streams carry the run-off from the sides of the narrow basin to the lake. A very low divide separates the south end of the lake from the north fork of Pit River, into which it has been known to overflow. The present lake surface is about 190 square miles in area, about 60 square miles of which is in Oregon.

SUMMER LAKE BASIN.

Summer Lake, about 70 square miles in area, is largely independent of local run-off for its supply, for Ana River, its principal feeder, has its source in at least five large springs that rise in the sediments at the north end of the valley. The total flow of these springs is very constant, being, as measured by Mr. I. Landes, of the Reclamation Service, 148 to 150 second-feet, or 7,400 to 7,500 California miner's inches of 9 gallons a minute. Even during the dry season of 1887–8 it is said not to have decreased noticeably. Buckhorn and Johnson creeks have like sources in the sediments of the north end of the valley, but their waters sink before reaching the lake. Along the western side of the valley numerous streams rising in the slopes above flow into the lake, but the total discharge of the sixteen that were flowing measurably in September, 1906, was only 250 to 300 miner's inches, or about 4 per cent of that of Ana River.

WARNER VALLEY STREAMS.

Into Warner Valley only three streams of any consequence flow. Honey Creek enters the valley at its western edge, near Plush; Warner Creek also enters from the west, at Adel, while Twelvemile Creek

flows into the south end of the valley at Warner Lake post-office. These are perennial streams, but they have only a small discharge, hardly sufficient to balance evaporation from the lake, which is now broken into several detached water bodies.

NORTHERN DESERT AREA.

In Christmas Lake Valley there are no perennial streams. Peter Creek, in the northern arm of this valley, is the nearest approach to a living stream, but even in the spring it often flows no farther south than its sink. Lost Creek is the largest stream in the northeastern part of the area visited, having a discharge of 10 to 15 inches in the fall of 1906. Northward it flows only to a playa near the base of North Glass Butte.

Three or four ranches have been taken up along the eastern side of Wagontire Mountain, where springs issue. Of these springs the largest is that at Antone Egli's, the water of which is used for irrigating alfalfa. Its flow in November, 1906, was 8 or 9 miner's inches. As this water has the highest electrical resistance of all of those tested, a sample of it was taken for analysis, the result of which is given on page 72 (sample B). The total solid content of only about 10 parts in 100,000, or 5.84 grains to the gallon, shows it to be a very pure water.

DISCHARGE MEASUREMENTS.

During the last two years gaging stations have been kept by the United States Geological Survey on several of the streams of the county, the estimated discharges of which are given below.

Estimated monthly discharge of Chewaucan River at Paisley,[a] Oreg., in 1905 and 1906.

Month.	1905.[b]				1906.[c]			
	Discharge in second-feet.			Total in acre-feet.	Discharge in second-feet.			Total in acre-feet
	Maximum.	Minimum.	Mean.		Maximum.	Minimum.	Mean.	
January	332	53	94.1	5,786	111	46	65.9	4,050
February	111	23	64.6	3,588	111	46	62.6	3,480
March	223	64	136.0	8,362	739	68	173.0	10,600
April	318	131	230.0	13,690	837	211	563.0	33,500
May	290	198	238.0	14,630	1,000	387	670.0	41,200
June	318	53	154.0	9,164	649	259	415.0	24,700
July	64	23	33.2	2,041	234	37	110.0	6,760
August	23	19	19.5	1,199	37	29	30.5	1,870
September	36	19	23.5	1,398	68	29	37.9	2,260
October	36	23	28.5	1,752	46	29	37.3	2,290
November	36	23	29.7	1,767	68	37	47.8	2,840
December	223	23	70.8	4,353	81	23	52.1	3,200
The year[d]	332	19	93.5	67,730	1,000	23	189	136,750

[a] Gaging station established January 4, 1905. I. Landes, hydrographer.
[b] Report of Progress of Stream Measurements for 1905. Water-Supply Paper No. 176, U. S. Geol. Survey, p. 135.
[c] From unpublished records of United States Geological Survey furnished by J. C. Stevens, district hydrographer, Portland, Oreg.
[d] Ice gorge January 10–31; discharge, assumed 77 second-feet. Ice conditions for remainder of winter months not known; open channel rating table applied.

Estimated monthly discharge of Silver Creek near Silver Lake,[a] Oreg., in 1905 and 1906.

Month.	1905.[b]				1906.[c]			
	Discharge in second-feet.			Total in acre-feet.	Discharge in second-feet.			Total in acre-feet.
	Maximum.	Minimum.	Mean.		Maximum.	Minimum.	Mean.	
January	70	24	36.8	2,263	50	80	24.1	1,480
February	137	21	43.9	2,438	78	7	27.6	1,530
March	155	54	73.9	4,544	212	10	40.4	2,480
April	203	46	89.9	5,349	530	57	320	19,000
May	87	27	47.2	2,902	246	43	118	7,260
June	39	21	27.8	1,654	106	21	45.7	2,720
July	21	13	16.7	1,027	86	12	31.3	1,920
August	19	15	17.1	1,051	15	12	12.5	769
September	19	15	15.4	916	15	12	12.9	768
October	21	15	15.7	965	13	12	12.0	738
November	42	13	21.4	1,273	26	5	12.7	756
December	36	13	21.6	1,328	31	5	13.5	830
The year[d]	203	13	35.6	25,710	530	5	55.7	40,251

[a] Station established December 29, 1904. I. Landes, hydrographer.
[b] From Water-Supply Paper No. 176, U. S. Geol. Survey, p. 129.
[c] From unpublished records of United States Geological Survey, furnished by J. C. Stevens, district hydrographer, Portland, Oreg.
[d] Ice is known to form at this station during winter months, but the observer failed to note the length of time that ice conditions existed during 1905. The open channel rating table was applied to the winter months without correction.

Estimated monthly discharge of Bridge Creek near Silver Lake,[a] Oreg., in 1905 and 1906.

Month.	1905.[b]				Month.	1906.[c]			
	Discharge in second-feet.			Total in acre-feet.		Discharge in second-feet.			Total in acre-feet.
	Maximum.	Minimum.	Mean.			Maximum.	Minimum.	Mean.	
January 21–31	8.1	2.0	4.55	99	January	21	11	16.6	1,020
February 1–19, 24–28	10.0	1.2	4.33	206	February	21	11	17.1	950
March	2.8	1.2	2.23	137	March	14	4	10.4	640
April	6.6	.8	2.53	151	April	23	7	10.5	625
May	12.9	1.3	7.79	479	May	29	14	21.1	1,300
June	15.2	3.0	10.6	631	June	22	15	18.7	1,110
July 1–6	3.0	.6	2.18	26	July 1–21	25	6	.....	.....
August 7–31	.8	.2	.46	23					
September	.7	.6	.66	39					
October	.9	.6	.73	45					
November	1.5	.7	.95	57					
December[d]	1.3	.2	1.00	61					

[a] Station established January 21, 1905. I. Landes, hydrographer.
[b] From Water-Supply Paper No. 176, U. S. Geol. Survey, p. 131.
[c] From unpublished records of United States Geological Survey, furnished by J. C. Stevens, district hydrographer, Portland, Oreg.
[d] Ice conditions December 17–31; discharge estimated, 1.3 second-feet.

Discharge measurements of Bear Creek near Silver Lake,[a] Oreg., in 1905.[b]

January 24	14.4	August 7 [f]	6.3
February 23 [c]	23.6	October 4	5.0
March 17 [d]	11.7	October 24	6.4
May 31 [e]	50.0	November 11	6.8
June 15	46.0		

[a] Station established January 21, 1905, at County Bridge. I. Landes, hydrographer. Results for 1906 unsatisfactory, and station discontinued.
[b] From Water-Supply Paper No. 176, U. S. Geol. Survey, p. 131.
[c] 500 feet below bridge.
[d] 400 feet below bridge.
[e] 100 feet above bridge.
[f] 300 feet below bridge.

Approximate annual discharge of the several streams of Lake County, Oreg., in 1905 and 1906.

Stream.	Approximate area of drainage basin in square miles.	1905.		1906.	
		Discharge for year in acre-feet.	Run-off in inches (to nearest tenth).	Discharge for year in acre-feet.	Run-off in inches (to nearest tenth).
Chewaucan River	272	[a] 67,730	4.7	[a] 136,750	9.4
Silver Creek	221	[a] 25,710	2.2	[a] 40,251	3.4
Bridge Creek	45	[b] 2,100	.9	[b] 6,650	2.8
Bear Creek	62	[b] 12,600	3.8	[c] 18,500	5.6
Crooked Creek	95	[c] 12,000	2.4	[c] 17,750	3.5
Coyote Creek	47	[c] 2,000	.8	[c] 3,300	1.3
Moss Creek	16	[c] 1,500	1.8	[c] 2,200	2.6

[a] From measurements of United States Geological Survey.
[b] By interpolation in the incomplete records of the United States Geological Survey.
[c] Estimated by comparison with discharges of Silver and Bridge creeks.

CHARACTER OF DISCHARGE.

In the monthly stream-discharge tables a fact worthy of mention may be noted. The time of greatest discharge of Chewaucan River is during April and May, its maximum being reached in the latter month. Silver Creek, being smaller and draining less mountainous country, would be expected to reach its maximum flow somewhat earlier, as it does, in April. But Bridge Creek, with a drainage basin of only 45 square miles, does not reach its highest period until May or June. This is probably to be accounted for by the fact that its supply comes chiefly from the north slope of Yamsay Mountain, where melting of the snow is slower than on the eastern slopes drained by Silver Creek.

Another peculiarity, not explainable from the data at hand, concerning Bridge Creek is that, although judging from the records kept at Lakeview and Silverlake the precipitation was only about 50 per cent more in 1906 than in 1905, the total discharge of this stream, as shown by the figures of approximate discharge given above, was more than three times as great, so that the ratio of run-off to precipitation within its basin about doubled. For the other streams the discharge during 1906 was, like the precipitation, roughly 50 per cent greater than that of 1905, so that the run-off ratio remained about the same during these two years.

RUN-OFF RATIOS.

Much study has been given to the relation of rainfall to run-off, and attempts have been made to deduce formulas for determining their ratios in different regions. So many complex conditions influence the run-off, such as amount, intensity, and distribution of rainfall, nature of soil, slope of surface, area and configuration of basin, as well as

geologic structure, forest, wind, etc., that the ratio can be stated only in a very general way.

Newell[6] gives general curves showing the ratio, and they indicate that for a region like southern Oregon, in which the precipitation in the higher drainage basins is probably from 15 to 20 inches, the run-off is usually between 3 and 5 inches.

The amount of run-off deduced in the table on page 35 from the estimates of approximate discharge departs from these figures in several cases, but in those records that are considered the most reliable the run-off agrees fairly well with this general ratio of one-fifth to one-fourth.

Since no records of precipitation have been kept on the higher areas, the apparent departures from this ratio may fairly be assumed to be due, in part at least, to uneven distribution of the snowfall within the several drainage basins.

EFFECT OF FORESTS.

Because rainfall is most abundant in forested regions many believe that forests exert an influence favorable to precipitation. While they may have an appreciable cooling effect on the air, aiding to reduce the temperature below the dew point and thus to produce rain, the evidence on this matter is so conflicting that definite conclusions can not yet be reached. It seems more reasonable, however, to believe that abundant rainfall is the great factor in controlling the distribution and density of forests, rather than that the forests cause greater rainfall.

Although the relation of forests to rainfall and run-off is a complex problem, into which enter the factors of climate, topography, geography, and geology, there is no doubt whatever that the forests store a part of the rainfall in their spongy soil and loam, whence it enters the streams gradually rather than suddenly, and that they protect the accumulations of snow from rapid melting and evaporation; therefore the preservation of the forests is of vital importance.

A large part of the precipitation on all areas is returned to the air by evaporation. From the tree crowns immediately after a storm this return is, of course, very rapid, but the amount thus evaporated is only a small fraction of the total precipitation. From the forest-covered soil evaporation is comparatively slow, because the soil is protected from sun and wind, and the amount of moisture absorbed by a forest to supply the plant needs is probably less than that needed by the average agricultural crop. The total quantity annually returned to

[6] Ratter, George W., Relation of rainfall to run-off: Water-Supply Paper No. 80, U. S. Geol. Survey, 1903, p. 9.

[7] Newell, F. H., Results of stream measurements. Fourteenth Ann. Rept. U. S. Geol. Survey, pt. 4, 1894, p. 151.

the atmosphere from a forest by transpiration through the stems and leaves and by evaporation from the trunks and from the soil has been estimated at 75 per cent of the precipitation, while for fields of cereals and grasses it may be even more, in regions where from a bare field the evaporation may be only 30 per cent of the precipitation.[a] But the amount of moisture annually evaporated from forest-covered soils and transpired by the trees themselves is only about half as great as that from open fields having a moderate covering of herbage.[b]

On the other hand, in regions of scanty rainfall, where a short wet season is followed by a long dry one, evaporation from the forest soil may go on slowly throughout nearly the whole year, while in the open, during a great part of the year, there is very little moisture to be evaporated and therefore little loss by transpiration from the scanty herbage, so that in such a case the forest-covered soil may lose more moisture by evaporation and transpiration than the open field. The spongy forest soil also, by retaining a large part of the scanty rainfall, lessens the stream flow from such an area. This is notably the case in many parts of the arid West.

The greatest collateral usefulness of a forest, however, lies in its power to regulate the run-off and to maintain a more equable flow of the streams. This it does by decreasing the surface run-off of flood waters and by increasing the seepage run-off from the saturated soil, which is the water that sustains stream flow. This is of far greater benefit than would be the extra water carried off by streams to the valleys below if the slopes were cleared. Indeed, usually the greater run-off of cleared areas is in the form of violent and destructive floods. A regulated flow, even though the total discharge may be less than the sum of a succession of floods, is vastly more beneficial, for "It is the amount of water that passes into the soil, not the amount of rainfall, that makes a region garden or desert."[c]

Minor but important effects of forests are protection from wind erosion as well as from erosion by water, prevention of snow slides in some localities, moderation of extremes of temperature, and, perhaps, distribution, if not increase, of precipitation.

LAKES.

CHANGES IN SURFACE LEVEL.

On account of the shallowness of the water bodies of Lake County the water level of the lakes can fall but little without destroying them. Such occasional dryings up have no doubt occurred within recent times. The best-known instance is that of Silver Lake. In

[a] Fernow, B. E., Economics of Forestry, New York, T. Y. Crowell & Co., 1902, p. 438.
[b] Ibid, p. 437.
[c] Toumey, James W., The relation of forests to stream flow: Yearbook U. S. Dept. Agriculture for 1903, p. 288.

1879 Cope found Thorn Lake dry and Silver Lake low, but Russell states that during the following three years the surface of Silver Lake rose 6 feet and in 1882 was confluent with that of Thorn Lake. As has been stated, in 1888–89 Silver Lake completely dried up, which required a change in level during these six or seven years of at least 10 feet, for Russell stated that in June, 1882, when confluent with Thorn Lake, it was only 10 feet deep. In 1890 it again began to fill, and during the fall of 1906 the gage board established by the Reclamation Service indicated about 13 feet, but it was not learned whether this was supposed to be the depth of the lake.

It is claimed that Thorn Lake is supplied only by precipitation and occasional overflow from Silver Lake. As such overflow does not take place every year, evaporation would more than counterbalance these two sources of supply, and it therefore seems probable that it is fed by springs beneath its surface, like those at Christmas and Fossil lakes. The effect of the dry season of 1887–88 on all of the lakes would be useful for comparison, but it is not known; it was only learned through hearsay that Summer Lake shrank little, if at all.

Noted changes in the level of Summer Lake are not recorded, but from the nature of the alkaline wastes along its eastern side it would appear that it is slowly shrinking.

The northern end of the Abert Lake basin is so nearly level that it is said that a strong south wind often forces the water back nearly 2 miles over the alkaline flat; so it seems very probable that seasonal changes shift the northern margin considerably.

Goose Lake experiences differences in its level, but fluctuates more slowly than the smaller lakes. The story that in the early sixties an emigrant trail crossed its valley at a place where the water is now several feet deep indicates that the lake was then smaller than at present, but a few years later it rose so as to extend several miles farther north than it now extends, and for a short time (in 1869) it overflowed southward down Pit River. Since then it has shrunk, and is apparently still growing smaller.

The litigation in Warner Valley strongly emphasizes the fact that this lake has been shrinking since 1860, but at what rate can not be said, as there are no recorded observations and seasonal differences obscure the slower general change.

The Alkali Lake drainage basin has an area of about 300 square miles, but it is all desert; no perennial streams exist in it, and consequently the depression, except for a few pools, is dry during a large part of the year.

ANNUAL SURFACE INFLOW.

With the meager discharge measurements given on pages 33–34 as a basis, the mean annual flow into each of the lakes has been estimated as well as may be, and comparison of inflow with drainage area and

lake surface has led to some interesting conclusions. The areas of the drainage basins and of the lake surfaces can be obtained approximately from the map (Pl. II). Aside from the discharge tables given, data for estimating the inflow to the several lakes are lacking; but by comparing the observed width, depth, and velocity of other streams with the measured ones, a rough estimate of the stream discharge into each basin has been made and the following tables have been prepared.

The average rainfall records of 16.73 to 17 inches at Lakeview and 10.06 to 10.4 inches at Silver Lake given on pages 15–16, are for periods of twenty-two years at Lakeview and thirteen years at Silver Lake; and it has been estimated[a] that averages based on such lengths of time may differ from the final average by only about 3 per cent and 5 per cent respectively.

The stream-gaging record for 1905 is that for a year of 9.92 inches precipitation at Lakeview and 7.78 (?) inches at Silver Lake, or only about two-thirds of the average; but for 1906 the precipitation was 19.24 inches at Lakeview and 11.58 inches at Silver Lake, figures not greatly exceeding the average. So for the purpose of estimating the flow into each lake, the observed and estimated discharge records for 1906 have been used, since they are probably as close to the average as can be approximated.

From the average precipitation records an annual total of 14 inches upon the open surface of Goose Lake has been thought reasonable, while 12 inches has been assumed as the average annual precipitation upon the surfaces of the lower lakes—Summer, Silver, and Abert.

All of the following estimates are necessarily very general, being based on general data; still, for the facts they are meant to indicate, it is thought that the figures given are sufficiently accurate.

The annual surface flow into the several lakes was computed from the following estimated stream discharges, which were based on the character and size of the drainage areas of the several streams, as compared with the streams whose discharges have been measured.

Annual discharge of streams flowing into Goose Lake.

	Acre-feet.
Cottonwood Creek	6,000
Drews Creek	18,000
Dry Creek	1,000
Stream in Warner Canyon	2,000
Bullard Creek	1,000
Kelly Creek	2,000
Sixteen streams in California with aggregate drainage area of about 250 square miles (taken from Alturas sheet of U. S. Topographic Atlas)	30,000
	60,000

[a] Rafter, George W., Relation of rainfall to run-off: Water-Supply Paper No. 80, U. S. Geol. Survey, 1903. p. 18.

Annual discharge of streams flowing into Abert Lake.

	Acre-feet.
Chewaucan River (measurement)	136,750
Crooked Creek	17,750
Coyote Creek	3,300
Moss Creek	2,200
	160,000

Annual discharge of streams flowing into Summer Lake.

	Acre-feet.
Ana River (150 sec.-ft., measurement)	109,500
Johnson Creek (20 sec.-ft.)	14,600
Total of other streams (10 sec.-ft.), partial measurement	7,300
	131,400

Annual discharge of streams flowing into Silver Lake.

	Acre-feet.
Silver Creek (measurement)	40,250
Bridge Creek (partial measurement)	6,650
Bear Creek (partial measurement)	18,500
	65,400

As before stated, the annual precipitation on the surface of Goose Lake was taken as 14 inches; on the surface of the other lakes, 12 inches.

EVAPORATION RATES.

In the following table it is shown that the ratios of the area of each lake surface to its drainage basin differ greatly, and that the annual increment, expressed in feet of water on its surface, is also apparently very different for the several lakes. On the assumption that evaporation balances the inflow, the increment also represents the annual evaporation rate.

Areas of lakes and lake basins, and annual surface supply.

Lake.	Area of lake surface in square miles.[a]	Area of drainage basin (including lake) in square miles.[a]	Ratio of lake surface to entire drainage basin.	Annual surface inflow plus direct precipitation into lake, in acre-feet.	Annual increment expressed as feet in depth over the lake surface.[b]
Goose	190	1,065	0.18($\frac{1}{5}$)	60,000 142,000 202,000	1.66
Abert	60	900	.07($\frac{1}{15}$)	160,000 38,400 198,400	5.17
Summer	70	550	.13($\frac{1}{8}$)	131,400 44,800 176,200	3.94
Silver	15	500	.03($\frac{1}{30}$)	65,400 9,600 75,000	7.81

[a] Taken from map by measurement with planimeter.
[b] Inflow plus direct precipitation (in acre-feet), divided by area of lake, in acres.

Evaporation experiments covering a period of five years at Fort Douglas, Utah, determined the yearly evaporation there as being 42.46 inches. As computed by the Signal Service, the rate at that place is 74.4 inches.[a]

From a series of observations upon the rate of lowering of the level of Crater Lake, and from experiments to determine the rate of evaporation from its surface, Diller[b] concluded that, allowing for escape by seepage, the average rate was about 53 inches annually, the surface reaching its highest level early in May and its lowest turning point about the 1st of October. Gannett some years earlier placed the rate of evaporation from this lake at 40 to 50 inches. Crater Lake is in nearly the same latitude as the water bodies of Lake County, but is 1,600 to 1,900 feet higher, and by virtue of the lower temperature of the surrounding air and because of its protecting walls, presumably is not subject to so rapid evaporation. Recent evaporation experiments at Keno, near Klamath Lake, Oregon, indicate an evaporation rate of about 40 inches annually at that place.[c]

Other evaporation data for comparison are very meager, but it seems that from the water bodies of Lake County the rate is probably somewhat greater than from Crater Lake, or than at Keno, which is more closely surrounded by forested mountains than are the water bodies of Lake County.

In estimating the increment to the four lakes considered, and hence the approximate annual evaporation from their surfaces, no account could be taken of escape by percolation or leakage from their basins, for there was nothing to indicate the amount thus lost, if any at all; neither could an estimate be made of the amount evaporated from the marshes. Leakage may perhaps account in part for the large apparent increment of 7.8 feet to so small a water surface as that of Silver Lake, and also for the fact that this lake dried up so quickly after the dry season of 1887–88. Evaporation from Pauline Marsh also no doubt materially lessens the apparent increment to this lake, a part of the stream discharge being evaporated before reaching the lake.

From Chewaucan Marsh there is also probably much evaporation, so that Lake Abert does not receive so great an increment as is credited to it.

Summer Lake, with the great springs of Ana River pouring into it, has an apparent increment of about 4 feet. The existence of the

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[a] Newell, F. H., Results of stream measurements: Fourteenth Ann. Rept. U. S. Geol. Survey, 1894, p. 154. The results of experiments at Fort Bliss, Tex., given with those of Fort Douglas, are not quoted here, as they are for a region of higher mean temperature than that of southeastern Oregon.

[b] Diller, J. S., and Patton, H. B., Geology and petrography of Crater Lake National Park: Prof. Paper No. 3, U. S. Geol. Survey, 1902, p. 61.

[c] Clapp, W. B., and Hoyt, J. C., Progress of stream measurements for 1905: Water-Supply Paper No. 177, U. S. Geol. Survey, 1906, p. 242.

great springs feeding it renders very plausible the theory that other springs than those known discharge into this basin. The marshy nature of Thousand Spring Valley, however, indicates that this concealed supply may be by seepage over a considerable area, rather than by concentrated flowing springs. This assumption is strengthened by the fact that, according to notes of the Reclamation Service, on August 17, 1904, the discharge of Ana River near its source was only 155 second-feet, while near its mouth the discharge was 179 second-feet, indicating the accession to it of seepage waters or waters from other springs.

Rate of evaporation is a subject comparatively little studied as yet; results of experiments are meager, and the methods employed are unsatisfactory. Observations on the rate from pans or from inclosed basins usually give figures too large. It seems, however, that the rate from the water bodies of Lake County is probably greater than that observed at Keno—about 40 inches, and possibly more than 53 inches, the rate given by Diller for Crater Lake; but in the following discussion the conservative estimate of 40 inches will be taken.

SUBSURFACE INFLOW TO GOOSE LAKE.

Goose Lake, it will be noticed from the table on page 40, occupies one-fifth of its entire drainage basin. A glance at the index map (Pl. I), on which the limits of the several lake basins under discussion are shown by dotted lines, will emphasize the disproportionate area of Goose Lake with respect to its drainage basin, as compared with the other lakes. Its estimated supply or increment is only 1.66 feet (19.92 inches) annually, and the consequent evaporation rate is seemingly a little less than one-half of that assumed, which is almost certainly not the case. Neither leakage from the basin nor evaporation from the marsh land near Lakeview can be assumed to account for this discrepancy, for the problem is one involving not an excessive loss but a greater inflow than is in evidence.

It is recognized that the estimate of the surface inflow to Goose Lake may be 100 per cent or more in error, but even if the inflow is twice as great as has been assumed it will not materially affect the result, giving an apparent increment (and evaporation rate) of only 2.15 feet (25.8 inches) a year, for the surface inflow from the tributary streams is so much less than the direct precipitation on the lake surface that doubling the former does not greatly change the amount chargeable to evaporation.

The best explanation left to account for the discrepancy seems to be that the lake has a great constant source of supply beneath its surface. The several hot springs along the eastern side of its valley render it not improbable that other waters rise along the fault zone

that is believed to exist here and supply the needful extra inflow. With an annual increment of 2.15 feet, which assumes twice the inflow from surface streams that was considered in the table on page 39, a supply from subsurface springs of about 144,000 acre-feet annually, or nearly 200 second-feet, is necessary to admit of an evaporation rate of 40 inches.

If the computed inflow from the tributary streams, 1.66 feet, be taken as a basis, and an evaporation rate of 4 feet be assumed (which seems reasonable from the more open nature of the Goose Lake basin as compared with conditions at Keno), the necessary supply becomes nearly twice as great. Even the smaller of these estimates is a larger amount than the discharge of Ana River and may seem a great deal to be supplied by springs beneath the surface of the lake; but the Ana River springs would flow nearly the same if Summer Lake extended northward so as to submerge them, and they probably did flow even stronger than they do now when the lake occupied its entire basin.

Fall River, 70 miles southwest of the lower end of Goose Lake, has its source in springs discharging 1,500 second-feet, or ten times the flow of Ana River.[a]

In the above discussion of the water bodies the most interesting thing brought out is this apparent great subsurface supply of Goose Lake. While the reasoning is admittedly based on little concrete data, the weakest point, that of the amount of its surface inflow, is shown to be really a minor factor in the computation, and hence the deductions are considered worthy of presentation.

HYDROLOGY.

GENERAL STATEMENT.

As distinguished from hydrography, which deals with the streams and their flow, the hydrology, or underground waters, of the county will now be discussed.

Waters that exist beneath the surface of the earth may in general be separated into two classes—those that are found in unconsolidated material, relatively near the surface, and those that circulate within consolidated rocks, generally at greater depths. Between the typical examples of each there are many differences, but in less well differentiated cases there may be no good lines of distinction, so that some subsurface waters might well be placed under either head.

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[a] Hoyt, J. C., and Clapp, W. B., Progress of stream measurements for 1905: Water-Supply Paper No. 177, U. S. Geol. Survey, 1906, p. 133.

SHALLOW WATER.

UNCONSOLIDATED DEPOSITS.

That usually considered as ground water is found at moderate depths below the surface, in the gravels, sands, and silts of stream valleys, the alluvial material at mountain bases, or the accumulated sediments of lake valleys. In many regions, also, the decay of the country rock to a residual soil results in a loose porous layer that catches and holds a part of the rainfall and furnishes a supply of water for shallow wells.

Thickness and processes of formation.—The depth of loose material, either transported or produced in place by disintegration, depends on the climate, the character of the rock, and other factors, as well as on the surface features of the land. In humid climates, where vegetation is rank, rapid decay of the rocks takes place, this decay being aided by the organic acids formed in decomposing vegetal matter, by the abundant water that carries them downward, and by the disintegrating gases, like oxygen, that the water often contains. J. W. Spencer[a] states that in the region about Atlanta, Ga., the rocks are "completely rotted" to a depth of 95 feet, while "incipient decay" may reach to 300 feet; and it is estimated that in some parts of Brazil such agencies have caused the decay of granite to a depth of 1,000 feet or more.

In arid regions, where conditions are less favorable to rock decay through the action of chemical agents, rock removal and the resulting accumulation of débris are largely physical processes. Rapid changes of temperature break up the rock masses, because of the unequal expansion of the minerals of which they are composed, while the winds and the occasional torrential rains carry the disintegrated material to the lower areas, where it accumulates as talus, alluvium, loess, or lacustrine deposits. In addition to its function as a transporting agent, wind also acts powerfully in certain localities as an agent of erosion. The strong wind, laden with particles of dust and sand, becomes an effective natural sand blast and wears away exposed rock surfaces with great rapidity, and the fine particles thus removed accumulate as a part of the mass of loose material in the lowlands.

Ground-water level.—Where the soil has accumulated to sufficient thickness as a result of any or all of these processes, direct precipitation and the inflow from streams keep it saturated below a certain level, except in the most arid districts. This ground-water level is not fixed, but varies with the seasons and with the supply. Its surface has a very definite relation to the land surface, which it resembles in a general way, but it does not rise so high in the hills and often does

[a] Geol. Survey Georgia, 1893, p. 82.

not sink so deep in the valleys. Where the land surface intersects the surface of the ground water, as in deep valleys or gorges, springs issue, and as the ground-water level varies with the season these springs fluctuate, drying up when the level of their supply falls below the bottom of the valley and increasing their flow when the ground-water level rises. It is upon such water, saturating at least the lower portions of accumulations of loose material, that nearly all shallow wells depend.

In south-central Oregon the processes of soil formation have made but little progress. On the forested mountains the underlying rock is nearly everywhere in evidence, being covered in most places with only a foot or two of soil. All of the plateaus are rocky, with scarcely enough soil covering to give foothold to the scanty growth of sage. In the valleys, however, there is a fairly deep mantle of soil, an accumulation due chiefly to the contributions of small streams and to material brought by the winds from the higher plateaus. In these sands and silts is found all of the ground water that has thus far been developed in Lake County.

In many localities no definite data were to be had from which to estimate the thickness of such accumulations in the several valleys, but it is thought that in Silver Lake and Christmas Lake valleys it may reach a maximum of between 100 and 200 feet, while in some of the other basins it may be two or three times this depth.

ARTESIAN CONDITIONS IN LAKE AND STREAM DEPOSITS.

Water under sufficient pressure to bring it to the surface when properly tapped is sometimes found in old lake valleys. Streams flowing down from the surrounding slopes brought to the ancient lake alluvial material, which was assorted by the action of the lake water, the coarser being deposited first along the borders, while the finer was held longer in suspension. This assorting action of the water, causing deposition first of the sand and gravel along the margin and later of the finer sediments over these, resulted in the formation of wedgelike layers of sand and gravel, thinning out toward the center of the lake and alternating with layers of fine silts. The drying up of such a lake may leave a fertile valley, underlain by interbedded coarse and fine material, the coarser, thicker, looser beds being exposed in places along the edge of the valley, while the finer materials serve to confine percolating water to them. Thus storage reservoirs in lacustrine material are formed that will supply flowing wells sunk in the lower parts of the valley. The north end of the Colorado Desert, in southern California, is such a valley. Flowing water is obtained in it, chiefly from sand and gravel that underlies the surface at a depth of 450 to 1,000 feet.

In southern California many of the streams are dry or nearly so during the greater part of the year, but each storm swells them to torrents that carry down quantities of material from the mountain slopes to the valleys, where it is dropped. A large share of the water also sinks in the lower slopes. This work of intermittent torrential streams has built up at the mouths of the canyons alluvial cones, which farther out in the valleys have merged together. Coarse and fine materials have thus become interbedded, and wedge-shaped masses of gravels extend into the lowlands. These are in some places underlain and overlain by finer, less pervious materials, and their bases extend far enough up the valley sides to give enough pressure to the water to bring it to the surface when wells are bored. It is from such a source that the artesian water of parts of southern California and of San Joaquin Valley is obtained.

DEEPER WATER.

CONDITIONS OF OCCURRENCE.

As distinguished from the water in the looser, unconsolidated material, there is water that circulates in the porous strata of the underlying rock masses. Typically the shallow water is limited downward by the upper surface of the bed rock upon which the sand and gravel in which it circulates are deposited, while the deeper water is to be found in this bed rock. Its occurrence here and the possibilities of its utilization for irrigation or other purposes depend upon several factors, among which the porosity of the rock is one of the most important. Sandstones, on account of their greater porosity, are the rocks in which deep water is most often found, but it may be found in any porous rock if the other requisite conditions are fulfilled.

STRUCTURES.

The structure or attitude of the rocks is also of very great importance, for upon this depend the circulation of the water, the pressure under which it may be stored, and its accessibility beneath any given area.

In regions of impervious beds alternating with porous layers that are suitably exposed, so as to allow the absorption of a part of the rainfall and snowfall, the structures most favorable to the existence of water under pressure are synclines and monoclines—that is, rocks bent into trough-shaped or saucer-shaped folds or given a general dip in one direction.

The syncline is the ideal structure for flowing wells. The water that enters the porous beds exposed along the edges of a given basin percolates downward toward the lowest portion of the basin, and, collecting there under the pressure of the water higher up in the porous strata, rises toward the surface when tapped.

Faults, or fractures of the rocks, are unfavorable to the collection of water, because the fault planes that break the water-bearing beds furnish it an easy means of escape.

Monoclines that are limited by faults—i. e., tilted blocks—are therefore not favorable structures for deep-water storage; but monoclines that are not broken, but pass into horizontal structure, or whose individual beds thin out down the dip, often yield flowing wells.[a]

As has been shown under the heading "Geology," Lake County is underlain by igneous rocks, a condition that at first thought seems fatal to the existence of available deep waters, for igneous rocks are usually compact and in irregular masses, allowing little opportunity for the storage of water or for its orderly circulation, so that it may be developed for economic uses. But the most extensive masses of these Lake County rocks are basalts, which spread out in widely extended sheets over the surface, so that their distribution is much like that of stratified rocks. Accompanying the basalt flows were volumes of fragmental volcanic material. This was also distributed as thin sheets or lenticular masses by streams and by deposition in lakes, and now appears as tuff beds associated with the basalts. This material is in many places more porous than a sandstone, and where other requisite conditions exist may serve efficiently as a water-bearing stratum. The vesicular basalt is itself sometimes regarded as being capable of storing water, but its vesicles are only isolated voids in an otherwise compact rock, not connected passages as in a porous material, and hence circulation of water is practically impossible in them.

In the great scarp that forms the eastern face of Steins Mountains, Russell[b] estimated that there are from 80 to 100 layers of coarse "sandstone" interbedded with the basalts; and in the many scarps of Lake County there are layers of light-colored porous material between the individual lava flows, although they are less numerous and less extensive than in the beds farther east.

Thus far no deep borings have been made in Lake County to determine whether these porous beds, in which alone rock water in valuable quantities may be expected, exist beneath the surface, and only by such tests can their presence or absence be proved. It is believed, however, that the probabilities are strong enough to justify the drilling of test wells in a few localities.

In other parts of this great lava area, especially in southern Washington, artesian water is obtained from sediments associated with the basalt, and it may also underlie portions of Lake County.

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[a] For further discussion of artesian basins see Water-Supply Papers No. 54, pp. 101–104; No. 78, pp. 10–14: No. 118, pp. 61–67; and Bull. No. 319.

[b] Russell, I. C., Artesian basins in southwestern Idaho and southeastern Oregon: Water-Supply Paper No. 78, U. S. Geol. Survey, 1903, p. 19.

In the Harney Basin, 130 miles east of Silver Lake, are the two following wells, which prove the existence of water under pressure beneath that valley, but for lack of proper care and casing these wells do not flow now. In 1893 a well was sunk to a depth of 848 feet about 6 miles southeast of Burns. Water was struck at 350 feet, which rose to the surface and overflowed, and at 840 feet another water-bearing bed was tapped; but in 1902 attempts to improve this well caused the flow to cease. In 1896 a 507-foot well was drilled near Harney, which at a depth between 200 and 300 feet struck water that rose to the surface, but the well was not cased and soon stopped flowing.[a]

In discussing the several valleys of Lake County the structural conditions in each will be considered in some detail and the evidence in regard to the probability of securing flowing artesian water will be given.

TEMPERATURES.

In the study of underground waters the temperature offers interesting and often most suggestive evidence. It has been determined by observations in deep wells and mine shafts throughout the world that below the surface layer, about 50 feet in thickness, which is affected by daily and seasonal changes, the temperature increases at a rate of 1° F. for each 50 or 60 feet in depth. So that when wells or springs yield warm waters and it seems likely that their temperatures are not due to exceptional conditions, like proximity to masses of rock heated by volcanic activity, or to a zone of faulting, an estimate may be made of the depth from which they rise. This can not be safely applied to waters that rise along fault zones, because the enormous friction accompanying the faulting produces high temperatures in the adjacent rocks and abnormally heats waters that rise in their vicinity.

In this respect 70° F. is sometimes taken as the temperature above which natural waters are classed as hot,[b] while between this figure and the mean annual temperature of the region they are classed as warm. Those springs whose waters are of about the mean temperature, or in winter below it, are classed as cold. This classification is a convenience only and can not be rigidly applied, because as will be at once realized, the same temperature that is called warm in northern latitudes might be classed as cool in equatorial regions, and, indeed, there are places whose mean temperature is above that of the so-called hot waters.

[a] Russell, I. C., Artesian basins in southwestern Idaho and southeastern Oregon: Water-Supply Paper No. 78, U. S. Geol. Survey, 1903, pp. 40–41.

[b] Peale, A. C., Natural mineral waters of the United States: Fourteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1894, p. 68.

THE LAKE VALLEYS.

WARNER VALLEY.

Warner Valley is a long, narrow depression that extends from north to south in the eastern part of Lake County, and continues into California as Surprise Valley. Its northern portion is only 6 or 8 miles wide, and is bounded on each side by the steep walls that have been described under the headings of "Topography" and "Structure" (pp. 9, 25.)

In the valley bottom there is a string of partially connected alkaline lakes about which are marsh areas that represent for the most part lands from which the waters of the lakes, which are slowly shrinking, have but recently withdrawn. There is both geologic and historical evidence of this shrinkage of the lakes, which are now but remnants of the water body that covered the floor of the whole valley during Quaternary time. Faint beach lines of this former lake are still to be seen in a few places along the sides of the valley, while the litigation mentioned on page 12 is a result of minor changes in level that have taken place within the last half century.

There are but few settlers in the valley, and the agricultural development is limited to small gardens and alfalfa patches and to the harvesting of wild hay from the marsh land as winter feed for cattle and sheep.

Three streams—Warner, Honey, and Twelvemile creeks—flow into the valley from the west or southwest. From each of these a part of the water is diverted for irrigation, but as the supply is small the area thus watered is inconsiderable. These creeks bring down a certain amount of débris and deposit it at the edge of the valley. Honey Creek especially has thus built up a large alluvial fan where it debouches into the lower lands, but the greater part of this material was probably deposited as a delta in the former lake, and this delta is now being rapidly dissected.

Little or no attempt has been made to develop the shallow ground water for irrigation. Water in apparent abundance is obtained in wells only a few feet in depth, but it is used only for domestic purposes and for stock. It is possible that rather deep wells sunk at the outer edges of the alluvial fans of the streams mentioned above would yield flowing water if properly cased, but this would be only in the lower lands, where water for irrigation is of least value. The widest area of cultivable land is in the northern part of the valley, where there are no perennial streams and the region is dry and covered with sagebrush. As elsewhere in the valley, water exists within this area at shallow depths, but it is somewhat alkaline, and it is improbable that this land could be successfully farmed with such irrigation water as could be developed locally.

The structure of Warner Valley is unfavorable to the existence of water under pressure in the porous beds of the basaltic series underlying the alluvium and lake sediments. The valley owes its origin to faulting, the southern portion being a dropped block faulted on both sides, as shown in the cross section Pl. X, page 66.

The scarp that limits the valley on the west dies out near Plush, so that the northern part of the valley is formed by the lower portion of a tilted block, as shown in the section through Chewaucan Marsh (Pl. X). It has been shown (p. 47) that such faulting is unfavorable to the occurrence of ground water under pressure; hence it is not worth while to undertake deep drilling in the rock underlying this valley in the hope of obtaining flowing water.

GOOSE LAKE VALLEY.

Goose Lake Valley lies in the southern end of Lake County. The lower two-thirds of the lake is in California, but by far the greater portion of the valley is in Oregon, north of the lake. On the east the steep-faced extension of the Warner Mountains borders the valley at only 2 or 3 miles' distance from the lake, but to the north and northwest the surrounding slopes are more gentle and give way to low hills on the southwestern side.

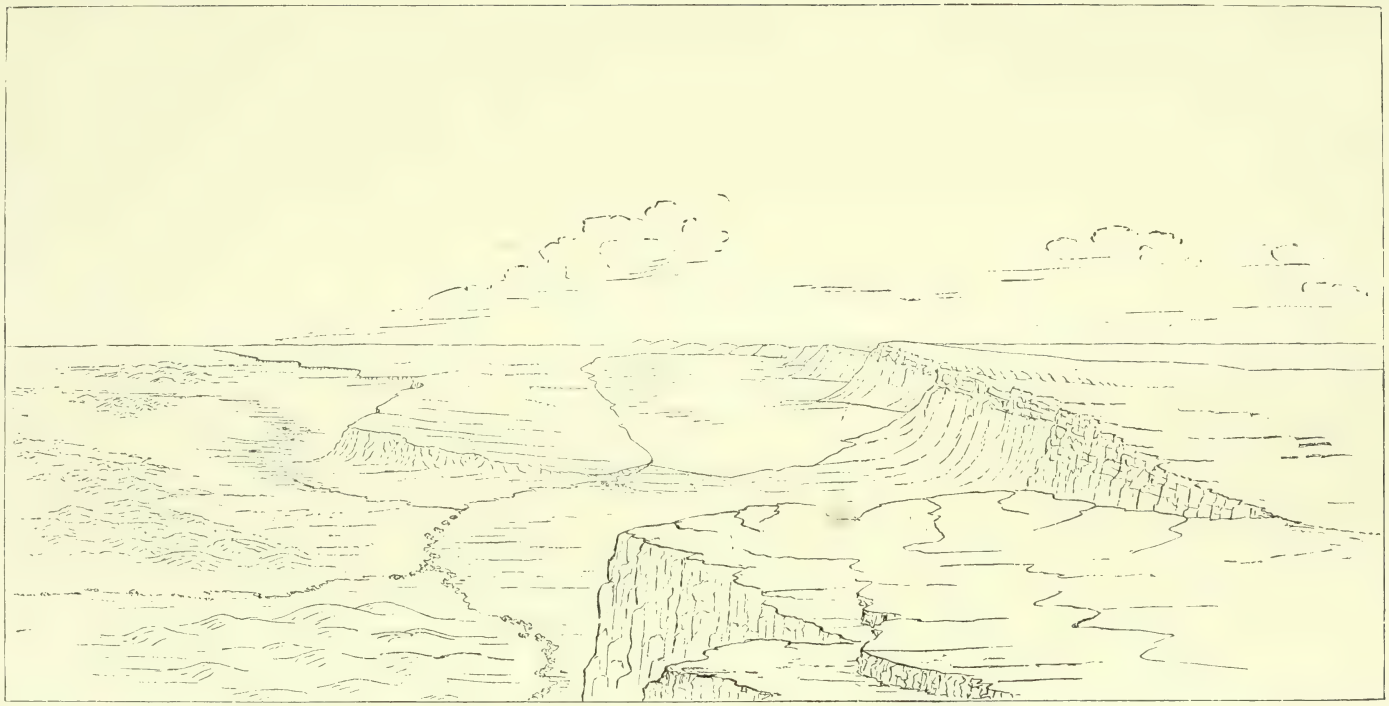
Around the north end of the lake there is marsh hay land, but the upper part of the valley is practically all unreclaimed and is used only for grazing purposes.

Nearly all of the people in this valley live on its eastern side. Lakeview, the county seat, is situated at the edge of the valley a few miles beyond the north end of the lake. Fifteen miles south of it is the town of New Pine Creek, at the Oregon-California line, and between these two towns there are a number of ranches; but on the west and the north sides of the valley there are only a few scattered homes.

Near New Pine Creek a number of orchards and gardens are irrigated by the small streams along the eastern side of the lake, and these, together with shallow wells, supply all of the water at present needed. At Lakeview a good supply of water for the town is obtained from springs in the hills above, and the few private domestic wells reach only to the ground-water level, so at no place in the valley has an attempt been made to get deeper water in the valley sediments.

At the north end of the valley gravel beds have been deposited. These are probably saturated below the ground-water level, and water could be developed by pumps, but the returns to be expected would scarcely warrant this means of irrigation, at least for some years to come.

The filling in of the valley depression by wash from the surrounding slopes, the presence of the lake, much smaller now than in the



SKETCH OF LAKE ABERT, FROM THE SOUTHEAST.

past, and the constant deposition of fine sediments in this lake are genetic conditions favorable to that alternation of coarse and fine deposits essential to artesian flows. It is probable that cased wells of the California type (described on p. 78) and less than 500 feet deep, if sunk in the lowest parts of the valley, west of Lakeview, would yield flowing water; but it is not thought that such water can be developed in the higher, northern part of this valley.

On the eastern edge of the valley, near Lakeview, three hot springs rise, with a temperature of about 173° F. These serve to strengthen the topographic evidence that this, like Warner Valley, has been produced by a faulted block, having the character of the dropped keystone of an anticlinal arch, as shown in the cross section on Pl. X. In such a structural basin, whose origin is almost fatal to the existence of rock water under artesian head, it would be useless to attempt to obtain flowing wells by deep drilling if ever water should be needed for agricultural purposes.

ABERT LAKE BASIN.

In the central part of the county Summer Lake, Chewaucan Marsh, and Abert Lake are in a valley that was once occupied by a single great water body; hence these three now rather distinct basins are topographically one. Structurally, however, they are separate, and therefore they will be separately considered.

Abert Lake lies in the eastern, lowest depression of this valley, in the most typical structural basin formed by a tilted block in this entire region. On its eastern side a cliff rises from the water's edge to a height of more than 2,000 feet, while on the western side the gentle slope of the surface of the tilted block rises to the scarp overlooking Chewaucan Marsh, as is shown in Pl. VIII, reproduced from Russell's article on the region.

As its water level has lowered, the lake has left an extended area of marsh land at its northern end, but little or none along the steeper sides of its basin. This marsh land is controlled by the "X L" ranch, and is used for winter pasture, besides furnishing many tons of wild hay.

A strong spring of good water, 63° F. in temperature, rises at the ranch house and supplies abundant water for stock and for all domestic purposes.

In the northeastern portion of this basin there is some agricultural land where one or two families live, but little attempt has been made to develop water for irrigation. At a number of places along the western shore of the lake there are fresh-water springs of small volume. These are evidently fed by waters that accumulate on the monoclinal slopes between the lake and Chewaucan Marsh, seep down the dip of the basalts, and reach the surface at the lake border.

As there is so little land here possible of reclamation, and hence so little demand for a large water supply, and as, in addition, the geologic structure is so evidently unfavorable, it is scarcely necessary to say that the probability of the occurrence of available rock water under artesian head is very small.

SMALLER VALLEYS.

Near the head of Crooked Creek, about 12 miles south of Lake Abert, in a narrow valley known as Antelope Valley, there are a few settlers. The alluvial soil here seems deep and is capable of growing good crops, but as elsewhere, and under present conditions perhaps most profitably, the land is used mainly as pasture.

Along Coyote and Moss creeks there are also a few settlers, where the streams supply water for small gardens and orchards, and nearly all such small areas have long been occupied by homesteaders.

VALLEY OF CHEWAUCAN MARSH.

The valley occupied in large part by Chewaucan Marsh extends southeastward from where the river of the same name emerges from its canyon to within a short distance of Lake Abert. Its eastern border is the edge of the tilted block that dips under Lake Abert, while the western side is bounded by the steep slopes that separate it from the drainage basin of the river.

Paisley is situated on the banks of the river where it enters the valley. South of Paisley, along the edge of the valley, there are several ranches where grain, alfalfa, and fruits are grown, but north of the town there are no settlements.

The marsh land is under the control of two or three large cattle companies. The river water mostly sinks in this marsh, but by means of drainage canals the land is kept fairly dry, so that great quantities of wild hay are cut from it. Only at The Narrows is there much unproductive alkaline land.

An area of several square miles north of Paisley and the terraces south of the town, against the hills, are covered with gravel brought down by Chewaucan River. A section in this material is exposed at the river bank, just below the Paisley bridge, showing about 4 feet of this gravel overlying 6 or 8 feet of river sands, which in turn overlie finer material, probably lake sediments. A low alluvial divide separates the marsh from Summer Lake Valley, but a well-defined channel still exists in it, through which the two basins were formerly connected.

On the terrace land near Paisley a number of acres of alfalfa are irrigated by ditches that take water from the river a short distance up its canyon. Much land above the level of the present irrigating ditches, at both the northern and the southern ends of the marsh and along the western side of the valley, will be susceptible of cultivation

when water can be supplied to it, but at present it is used only for stock range. The greater diversion of the waters of Chewaucan River for this purpose would no doubt benefit the marsh land also, for much of it is too wet to permit easy harvesting of the wild hay. While it is probable that water for irrigating these higher parts of the valley can best be obtained from storage reservoirs in the upper course of the river, a number of small streams along the western side of the valley could be made to furnish a useful local supply. These streams usually sink in the alluvial fans at the mouths of their gorges, but when traced toward their sources in springs in the mountains above are found to have a considerable flow, which might profitably be piped or flumed to the lands along the edges of the valley.

Like most of the other valleys, that occupied by Chewaucan Marsh has been produced by faulting. The scarp on its eastern side is clear evidence of such movement there, and it is thought that similar deformation has taken place on the western side also, as shown in the cross section, Pl. X, but the evidence on this side of the valley is not so clear.

This structure of course precludes the probability of the existence of available water in the underlying rocks. But in the central part of the basin there is too great an abundance of surface water, the problem at present being rather one of regulation of the supply and of drainage than of the development of additional water; and, as heretofore stated, for irrigating the arid portions of the valley water can probably be best obtained from the river.

SUMMER LAKE VALLEY.

DESCRIPTION.

Summer Lake Valley resembles the basin of Abert Lake in being bounded on one side by a great scarp and on the other by more gentle slopes. On the north rise the slopes of the cross anticline separating it from Christmas Lake Valley, while southward the delta deposits of Chewaucan River divide it from the marsh lands of the river's lower course. The land between the south end of Summer Lake and Paisley is gravelly and is apparently not alkaline. At present it is too arid to be of value for agriculture, but by irrigation it can no doubt be rendered very productive.

STREAMS.

Along its western side, between the rim rock and the lake's edge, numerous streams furnish water for irrigation as well as for domestic purposes, and it is here that most of the ranches of this valley are situated. This is one of the mildest spots in the county, so that nearly all the common vegetables and many varieties of fruit are to be

found in its gardens and orchards; but the tillable land is limited to the narrow strip between the lake and Winter Ridge; hence its area is not great. In the northern part of the valley much of the surface is either arid, sandy, sagebrush land, or a greasewood flat. Near the lake the land is more moist, and here a few settlers have taken up claims, but most of the marsh land is controlled by stockmen.

SPRINGS.

Conditions of occurrence.—The largest and best known springs in this region are those that issue through the sediments near the northwest edge of the valley and give rise to Ana River, which flows southward about 5 miles, to Summer Lake. Near these springs the river channel has cut nearly 40 feet deep into the lake deposits, prohibiting easy utilization of its water, but farther down a small part is diverted for irrigation.

The marshy areas around the northern end of the lake are kept moist by numerous springs, some of which form only small marshy spots, while others give rise to streams, such as Buckhorn and Johnson creeks. The temperature of Buckhorn Creek was not measured, but it is said to be somewhat warmer than that of Ana River (66° F.), while that of the two springs supplying Johnson Creek is 10 degrees cooler, or 56° F.

At the Bonham ranch, on the eastern side of the valley, the temperature of the strongest flowing spring is 66° F., the same as that of the springs that supply Ana River. On this ranch, in what is known as Thousand Spring Valley, a number of acres are irrigated naturally by many small springs. By distributing the water through small ditches Mr. J. H. Bonham has reclaimed much of the greasewood flat on his ranch and has greatly increased the original area of marsh hay land, thus demonstrating what water alone will accomplish on these apparent wastes. The water, constantly rising and evaporating tends to increase the alkalinity of the soil, and is insufficient in quantity to permit drainage and the leaching out of the alkali, so that only the natural grasses and salt bushes grow readily. Of the many kinds of trees tried, only a few cottonwoods along one of the ditches have lived.

The tendency of the alkali to rise with the use of water is also shown on the ranches in the northwestern part of this valley, near Ana River. Cultivation and irrigation from shallow wells tapping only the ground water have in several instances caused the garden areas to become so alkaline as to prevent nearly all of the common vegetables from maturing.

At the north end of the valley, in Juniper Canyon, water rises, apparently from a canyon spring or one where water seeps out of a tufa bed exposed along the canyon side. This has only a small flow, and

it is improbable that any considerable amount could be developed here to irrigate the higher valley sides, but as it is the only spring of this character noted it is thought worthy of mention.

At the southeast end of Summer Lake the Woodward hot spring rises, with a temperature of 123° F. The flow in November, 1906, was about 2 miner's inches. The water is used for irrigating garden vegetables and for bathing purposes. The location of the spring is not far from the steep slopes of this side of the valley, and the occurrence is considered additional evidence of faulting here.

Origin of the Ana River springs.—There are additions to the flow of Ana River, probably by seepage along its banks, below the group of five or more large springs at its source that supply the greater part of its flow. Johnson Creek, east of Ana River, has a flow of perhaps 20 second-feet, and the springs of Thousand Spring Valley yield a large aggregate. All told, it is probable that at least 200 second-feet constant flow rises through the silts and alluvium in this end of Summer Lake Valley.

The question of the source of this water is one that interests all who visit the springs. The region is semiarid, and the drainage area tributary to Summer Lake is limited and clearly inadequate to supply the water yielded by the strong and remarkably uniform flow of the springs. It has been asserted that Silver Lake is the source of supply, but in the years when this lake dried away completely the flow from the springs did not appreciably lessen.

No large streams discharge directly into the Summer Lake basin, but Chewaucan River discharges into the same topographic depression just south of the alluvial divide that separates that basin from Chewaucan Marsh. It has been suggested that water from this stream, which sinks in the sands and gravels, may percolate northward through the porous material that fills the lake basin and, rising beyond the lake, supply the springs in question. But the total mean flow of Chewaucan River during 1906, a year of more than average precipitation, was only 189 second-feet, and the flow during the previous year, of less than average precipitation, was only 93.5 second-feet. The total average discharge of this stream then, is less than the yield of the springs; and much the greater part of this total flows out through Chewaucan Marsh to Lake Abert. The relative elevations of the Ana River springs and the mouth of Chewaucan Canyon are not known. If the springs shall eventually be found higher than the canyon mouth, this fact will at once prove definitely that Chewaucan River water can not be the source from which the springs are supplied. The evidence just given, however, is regarded as practically conclusive, but additional evidence in support of this conclusion is supplied by the temperature of the water of the Ana River springs. This issues at 66° F., which, if the usual increment of 1° above the mean annual temperature for each 50 or 60 feet in depth be accepted, indicates that the

water rises from more than 1,000 feet below the surface. It seems unlikely that the alluvium is this deep near the north rim of the valley, where the springs issue, hence it probably rises from porous beds in the underlying basalt.

The fault that separates Winter Ridge from the valley east of it, since it represents a fracturing of the beds, furnishes a passage upward for any water that may be circulating at depths in porous layers interbedded with the basalts. It is unlikely that this water comes from the eastward, because the known faults in that direction furnish drainage ways through which any confined water can escape, and the intermediate areas are arid.

West and southwest from Summer Lake, however, the topography does not indicate such faulting as is characteristic of the area eastward; it is indicative rather of open folding. Since much of this region is mountainous and timbered and receives a relatively high precipitation, as is indicated by the fact that it is the gathering ground for such large streams as Sprague and Williamson rivers, it seems a competent source of supply even for such large springs as those in question. If the open folding that is indicated exists here, it provides for the exposure of the porous beds in the lavas, so that the water supplied by precipitation may enter them. This folding may also provide sufficient head to force the water eastward up the Winter Ridge monocline into Summer Lake Valley.

Another explanation, which differs slightly from that just given, has been offered. The Summer Lake basin is considered to be a collapsed anticline—a block of the earth's surface that has dropped as a result of the stresses to which the crust has been subjected, and has broken away from the rocks on each side, which are now exposed as the scarps north and west of Summer Lake. It may be that the water of the Ana River springs and the other large springs nearby percolate northward from the region of the upper Chewaucan drainage basin, along the axis of this anticline, and escape to the surface through the faults that mark both the northern edge of the dropped block and the northern edge of Summer Lake Valley.

In both of these explanations the spring waters are regarded as waters that escape from the basalts through the passages that the faults provide. They differ in the assumed source and direction of percolation of these waters. Of the two, that which supposes that they originate in the country west and southwest of Summer Lake is regarded as the more probable.

ARTESIAN POSSIBILITIES.

Shallow water.—The evident saturation of the alluvial and lacustrine deposits over wide areas in the northern end of Summer Lake Valley by water that seeps to the surface or that rises in definite springs suggests the possibility of obtaining flowing water in this

locality by sinking relatively shallow cased wells from 100 to 500 feet in depth. These swampy conditions in areas of marked slope are familiar evidences of the existence of subsurface water under pressure sufficient for the development of flowing wells, and so strong is this evidence in certain parts of this valley that there can be but little doubt that the sinking of cased wells would prove a successful venture.

Whatever the origin of the water in the unconsolidated deposits, it is clearly present in some quantity. As it now rises naturally by seepage over wide areas, it is very harmful to the land, depositing as it evaporates great quantities of alkali, which unfits the soil for agricultural purposes. Wells sunk in the moist land should therefore bring about two beneficial results: First, the present numerous small springs would probably dry up, their yield being concentrated in the relatively few wells, so that it would be much more readily available for irrigation; and secondly, the drying up of these seepages would lessen the present rapid rise of alkali and would thereby render the present alkaline lands valuable. Thus the sinking of shallow artesian wells should accomplish both concentration of the water supply and drainage of the swampy land. Thousand Spring Valley and the basins of Buckhorn and Johnson creeks are favorable localities for experimental wells.

Deep water.—In the paragraphs on structure (p. 26) and on the origin of the Ana River springs (p. 55) it has been explained that Summer Lake Valley is probably due to the collapse of an anticline and the consequent dropping down of a great block of the basalts. The bed rock beneath the valley is therefore faulted, and whatever water may be circulating through it is not confined under pressure, but is permitted to leak out along the fault planes into the overlying alluvium. As already indicated, the water yielded by the great springs of this area probably has this origin. But this leakage is a condition unfavorable to the existence of water under pressure in the basaltic rock underlying the sands, gravels, and silts that make up the surface of the valley. It is not expected, therefore, that deep drilling would develop flowing water in the bed rock beneath the valley.

SILVER LAKE VALLEY.

Northwest of Summer Lake Valley, and separated from it by a divide about 500 feet in height, lies Silver Lake, in the southern end of its basin. The lake itself is bounded on the east and on the west by scarps, but northward the valley opens out into a wide area of marsh, beyond whose borders there is much nearly level sagebrush land, at present dry, but cultivable and valuable if water can be applied. From the gentle slopes to the west and southwest three streams, Silver, Bridge, and Bear creeks, more definitely described on pages 31 and 35, flow into Pauline Marsh and thence into the lake. On the north

and east Conley Hills and their southward extension separate the valley from the larger Christmas Lake Valley. Topographically, however, Silver Lake Valley is really a part of this wider area, bein connected with it by a broad, low passage extending eastward to Thorn Lake, into which, at periods of very high water, Silver Lake overflows.

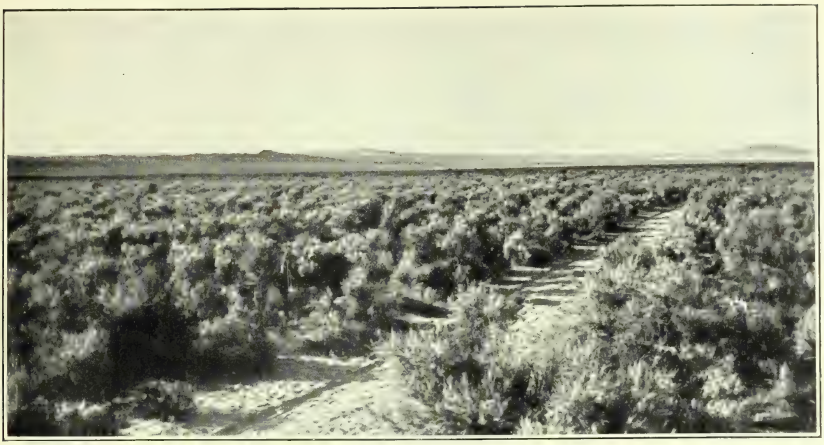
Like other areas of similar character, Pauline Marsh is given over to the growth of native grasses that are cut for hay, while drainage ditches carry off much of the superfluous water southward to the lake. The sagebrush land beyond the limits of the marsh can be made productive by irrigation, but at present it is used mainly as a stock range. Only from Bear Creek is water diverted to any extent for irrigation, and this is used only in the extreme western part of the valley.

On the low slopes of the south side of the valley a few springs have produced green patches of pasture land and furnish watering places for the range animals. The largest of these, Thomson and Murdock springs, 3 miles southeast of Silver Lake, flowed about 9 and 25 miner's inches, respectively, in October, 1906. Their temperature (48°) indicates that they are surface springs, not deep seated, though the water may rise from a porous bed along which it has percolated from the slopes of Hager Mountain.

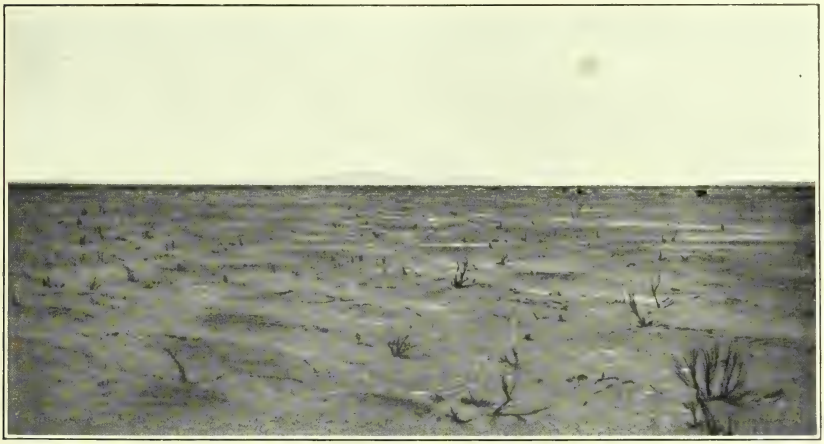
At the town of Silver Lake water is obtained in the 25 or 30 domestic wells in a soft porous material, usually at less than 30 feet below the surface. This seems essentially a subsurface flow, depending for its supply on the run-off from the surrounding slopes, for in winter, when the mountains are snow covered and the ground is frozen, the water level in the wells lowers. The water is of good quality, tests indicating only about 50 parts of alkaline salts in 100,000.

The only attempt to obtain deep water in the area examined has been made at Silver Lake. Mr. F. M. Chrisman, of this place, put down a 6-inch hole on the south edge of the town to a depth of about 250 feet, where the drill became caught and work was suspended. The usual subsurface water was found at a depth of 47 feet, but no other supply was developed, the drill being fast in dry vesicular basalt. A record of the well as kept by Mr. Chrisman shows a depth of 108 feet of clays, sands, and gravels, below which lies a thick tuff bed, probably like that at Fort Rock, underlain by basalt.

The structure of this basin seems more favorable to the finding of artesian water in the basalts than that of any of the other valleys of Lake County, except perhaps the Christmas Lake desert. On the west and south the slope of the lava beds is toward the valley. To the north also, along the base of Horning Bend, an exposure of tuff indicates that the dip is toward the valley, but on the eastern side this structure is not exhibited. The tuff composing these eastern hills is somewhat folded, but the dips are universally eastward, away from



A. SAGEBRUSH IN CHRISTMAS LAKE VALLEY.



B. AREA IN CHRISTMAS LAKE VALLEY CLEARED BY BURNING.

C. SAND SPRINGS.

Silver Lake Valley. What effect on artesian conditions this structure may have can not be stated definitely, but the Conley Hills and their extension in each direction probably separate it structurally from that of Christmas Lake Valley. Certainly the structural conditions are such as to justify a thorough test by the drilling of a well, 1,000 to 2,000 feet in depth, in the neighborhood of Silver Lake.

Satisfactory evidence of the structural relation of the Conley Hills to the regularly dipping basalts south and west of them, or to the horizontal basalts across the desert on the northeast, was not obtained, but the geologic cross section (Pl. X) is thought to represent the essential features of their relation to the valley on each side at its southern end.

CHRISTMAS LAKE VALLEY.

DESCRIPTION.

The largest valley of the Lake County area, and the one that seems capable of the greatest development, is that of Christmas Lake. Under this name is included all of the country northwest toward Fort Rock, as well as that around Christmas and Fossil lakes. It is an extensive, nearly level plain, 40 or 50 miles long from east to west, but much narrower from north to south. Unlike nearly all of the other valleys, it is not inclosed by steep walls; on all sides the slope to the surrounding basaltic "high desert" areas is gentle. On the west Fort Rock and Table Rock are prominent landmarks from nearly all parts of the valley, as is St. Patrick Mountain on the south, while on the north side of the valley the recent volcanic cones produce a low relief. Within the valley itself two low ridges rise above the sediments—a basaltic tongue extending southward from Bunchgrass Butte, and Sevenmile Ridge, a remnant of tuff like that at Fort Rock, that extends into the valley from its southern border.

Most of the valley floor supports a growth of sage, which in the more sandy areas is tall and dense, as in Pl. IX, *A*, but over much of the valley is not so thick as to interfere seriously with travel in any direction. In the more alkaline areas the surface tends to bake to a hardpan, over which there is only a scanty growth of grease brush.

Bunch grass and rye grass grow to some extent through nearly all of the valley land, and afford fair range for stock.

SETTLEMENT.

Two years ago there was only one family living in Christmas Lake Valley. In February, 1905, a party of a dozen or more men, neighbors and residents in Willamette Valley, were brought in by a "locator" and took up claims in the region north of Fossil Lake, now

locally known as "Sucker Flat." In the fall of the same year and in the spring of 1906 others came in and settled, chiefly around Christmas and Fossil lakes. Post-offices have been established at

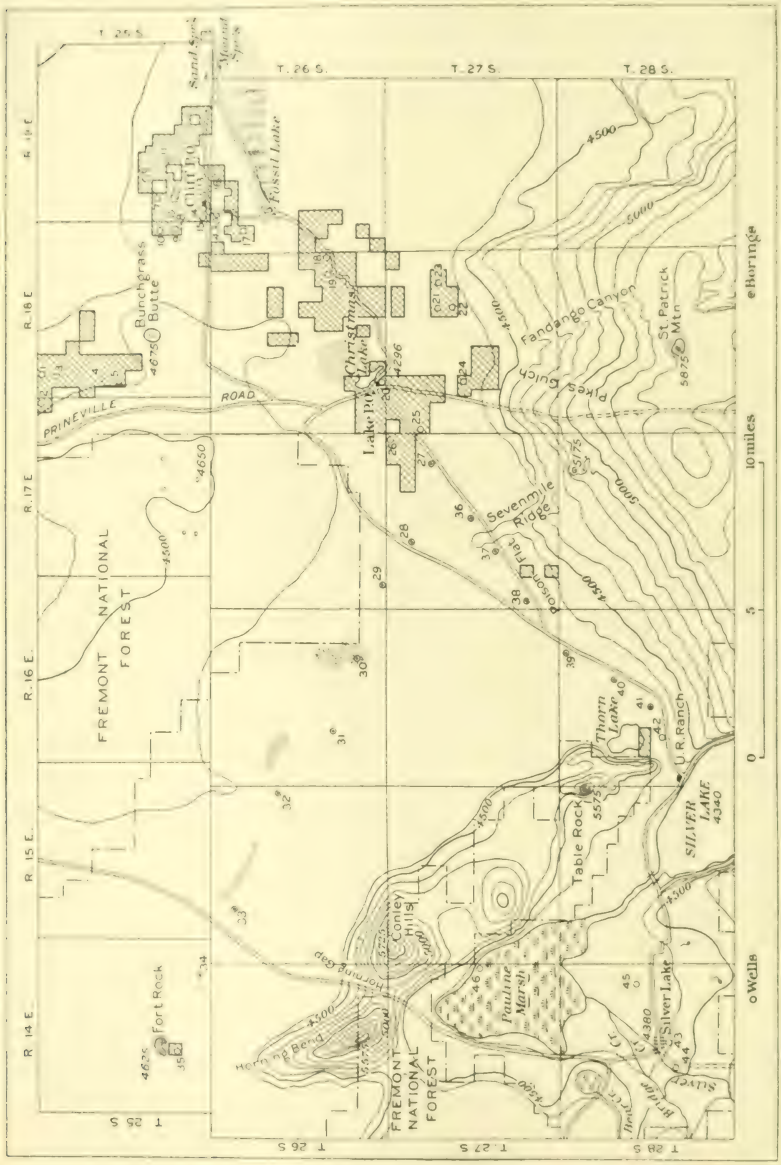


FIG. 1.—Map of Christmas Lake Valley, showing area filed on. Numbers indicate wells and test holes listed in table on p. 64.

Lake and Cliff (named after the locator who brought the settlers in), and a school district has been formed. Nearly all of the claims have been inclosed by substantial barbed-wire fences, the junipers of the

valley sides furnishing good posts for this purpose, and frame buildings have been put up.

About 120 claims had been filed on in the valley up to November 20, 1906. A number took up homesteads; others filed on desert claims. The approximate area filed on is shown in fig. 1.

METHODS OF CLEARING AND FARMING.

As most of the settlers began to clear land too late in the fall of 1905 to permit of burning, nearly all of the area planted the following spring was cleared by grubbing. Owing to the loose nature of the soil this is comparatively easy and gives a field nearly free from brush roots. During the summer of 1906 it was found that on a hot day, with a steady, moderate breeze, the denser patches of sage, once fired, burned completely, the fire often following the roots below the surface. In Pl. IX, *B*, is shown a burned area that was formerly covered with tall brush, like that in Pl. IX, *A*, which shows a view of the tallest, densest sage in the valley, on the sandy land 2 or 3 miles west of Christmas Lake. Dragging with a heavy beam has been tried where the brush is too thin to burn readily, but it is not brittle enough to make this method of clearing successful. Grubbing seems the most practical means on such areas.

Some of the homesteaders have filed on claims, intending to rely on dry farming with constant cultivation, as practiced in Kansas and elsewhere. Most of the grain and vegetables raised during the summer of 1906 (the first season that farming was tried here) matured without irrigation, and showed that the soil is fertile, though as yet rather deficient in humus, or vegetable mold. But 1906 is generally regarded as a favorable year. As indicated by the rainfall records, it was at least as wet as the average, and in drier years such excellent results can not be expected without irrigation.

Records from places of low rainfall show that there are more seasons with less than the average precipitation than there are wet years, for in a wet year there may be twice the average rainfall or more, to balance which would require a year of absolutely no rainfall. As this almost never occurs, a few very wet years serve to keep the average up, hence in arid regions there are more dry years than wet ones.

TENTATIVE IRRIGATION METHODS.

Desert claims.—The desert land acts of 1877 and 1891 provide that a maximum of 320 acres of land may be filed on as a desert claim, but within three years one-eighth of it must be under cultivation, and the whole area under irrigation, except high places evidently not

susceptible of irrigation;[a] so that those who have filed on desert claims in this valley realize that they must develop a large supply of water within the next few years.

Pumping.—Pumping has been considered, both by windmills and by distillate engines, from a number of shallow wells, or from large basins scooped out in the soil to ground-water level; for water is found at a shallow depth all through the valley, although not in great abundance nor of good quality. From local observation of the wind during the season of 1906 the writer believes that windmills can not be relied upon to any extent to furnish power, for, as in many other arid sections, during the hot, dry periods there is little or no breeze.

Even if a sufficient flow of ground water can be developed, which from the meager evidence at hand seems doubtful, the present cost of hauling in fuel is not warranted by the returns that may reasonably be expected from the land irrigated. The quality of the subsurface water should also be taken into account in considering its prospective use for irrigation, for it is all alkaline, at least all of the shallower water, which is all that has so far been developed, and although perhaps its use for the first few years would not be noticeably injurious to crops, its continued use, if not carefully managed, could not fail to be.

Storage reservoirs.—In other parts of the Northwest small storage reservoirs are constructed to conserve the run-off of the stormy season, both for irrigation and to furnish water for stock during the summer. The methods of constructing these reservoirs and the pre-

[a] Section 1 of the desert land laws, approved March 3, 1877, provides that any citizen of the United States, or person who has filed his declaration to become such, upon payment of 25 cents an acre may file a declaration that he intends to reclaim a tract of desert land, by conducting water upon it within the period of three years.

Section 2 designates "that all lands exclusive of timber lands and mineral lands which will not, without irrigation, produce some agricultural crop, shall be deemed desert lands."

Section 3 provides that this act shall apply only to California, Oregon, Nevada, Washington, Idaho, Montana, Utah, Wyoming, Arizona, New Mexico, North and South Dakota.

Sections 4, 5, 6, 7, and 8, approved March 3, 1891, further provide as follows: Section 4 provides that at the time of filing his declaration the party shall also file a map showing the mode of contemplated irrigation, section 5, that no land shall be patented under this act until at least $3 for each acre of the whole tract reclaimed shall have been expended in the necessary irrigation, reclamation, and cultivation. The party must file during each year, with the register, proof that the full sum of $1 an acre has been thus expended, and "If any party who has made such application shall fail during any year to file the testimony aforesaid, the lands shall revert to the United States, and the twenty-five cents advanced payment shall be forfeited to the United States, and the entry shall be cancelled. Nothing herein contained shall prevent a claimant from making his final entry and receiving his patent at an earlier date than hereinbefore prescribed, provided that he then makes the required proof of reclamation to the aggregate extent of three dollars per acre: *Provided*, That proof be further required of the cultivation of one-eighth of the land."

Section 6 provides that these later sections shall not conflict with any provisions of the act of March 3, 1877.

Section 7 provides that not more than 320 acres may be filed on under this act.

Section 8 states that this act shall apply also to the State of Colorado, and that "no person shall be entitled to make entry of desert land except he be a resident citizen of the State or Territory in which the land sought to be entered is located."

cautions that should be taken to insure their permanence are described in a recent bulletin of the Department of Agriculture.[a]

It seems that such reservoirs might prove of value in at least two localities on the edge of Christmas Lake Valley—in the slopes toward the sink of Peter Creek, and south of Christmas Lake, in Fandango Canyon. It is said that at times considerable flood water comes down these slopes, and even during the very general examination of the localities upon which this report is based several favorable reservoir sites were noticed.

In regard to the amount of water that could be thus stored little can be said, for data both as to the extent of the drainage areas and as to the amount of run-off are almost wholly lacking. The latter would no doubt vary between wide limits for different years, and probably a dependable supply could not be counted on to be thus stored for summer use; but this method of conserving water is used successfully elsewhere in the Northwest, and is at least worthy of consideration by settlers in northern Lake County.

In Wyoming and Dakota series of such reservoirs have been constructed in the prairies solely to provide water holes along the trails over which cattle are driven to shipping points. The scarcity of water holes in the high desert area between Christmas and Alkali lake valleys, after the natural sinks have dried up, has been the great drawback to this area as stock range. Low dams built with a comparatively small amount of labor across the lower ends of some of these sinks would greatly increase their storage capacity and the length of time they would serve as water holes, but it is doubtful if such watering places would last all summer. Even the deepest of these sinks were dry in September and October, and evidently had been so for two or three months. It is probable that in this area of indefinite drainage the run-off is so small a percentage of the precipitation, and the tributary drainage areas are so small, that such a means of conserving water for range animals would serve only to lengthen somewhat the high desert range period, but would not extend it throughout the summer. Thus it would be but a temporary expedient.

GROUND-WATER LEVEL.

In order to supplement the data concerning the ground-water level that were obtained from the shallow wells that have been dug, a number of 2-inch auger holes were put down in the unsettled portions of the valley. The locations of these test holes and of the wells examined are shown in fig. 1, and a table of the depths and water levels is given below.

[a] Herrman, F. C., Small reservoirs in Wyoming, Montana, and South Dakota: Bull. 179, Office of Experiment Stations, U. S. Dept. Agriculture, 1907. This bulletin may be obtained free of charge by request to Dr. A. C. True, Director, Office of Exp. Stations, U. S. Dept. Agriculture, Washington, D. C.

Wells and test holes in Christmas and Silver Lake valleys.

No. of well [a]	Owner.	Location.			Depth in feet.	To water in feet.	Material passed through.
		T. S.	R. E.	Sec.			
1	Mr. Beard	25	18	6	22	20	Lake silts.
2	(Test well)	25	17	1	30	(?) 29	Lake silts (water not used).
3	Mr. Gaskell	25	18	6	28	25	Lake silts.
4	J. W. Hanley	25	18	.....	35	25	Do.
5	Mr. Beard, sr.	25	18	.....	25	Dry.	0–18, silts; 18–25, rotten basalt.
6	Mr. Whitney	25	19	.....	12	11	Lake silts; a little rotten basalt at bottom.
7	Dr. Ewing	25	19	.....	10	9	0–6, silts; 6–10, rotten basalt.
8	Dr. Thayer	25	19	.....	12½	10	Lake silts.
9	Joe Kasperonez	25	18	25	12½	11	Lake silts; a little rotten basalt at bottom.
10	Frank Polte	25	18	25	4	Dry.	0–1½, silts; 1½–4, rotten basalt.
11	Mr. Wardall	25	19	28	13½	12	Lake silts.
12	James Wilson	25	19	29	12	8	Do.
13	(James McCurdy (3 wells).	25	19	32	16 14 12	10 10 10	0–4, silts; remaining depth, sand with streaks of clay.
14	John C. Green	25	19	31	12	10	Lake silts.
15	W. A. McHargue	25	19	31	13	11	Do.
16	Mr. McCurdy	26	19	.....	17	15	Do.
17	Mr. Brown	26	19	.....	11½	9	Lake silts; a little basalt at bottom.
18	Mr. Lanning	26	18	.....	26	24½	Lake silts.
19	M. W. Richmond	26	18	.....	31	25	Do.
20	A. W. Long	26	18	.....	22	20	Do.
21	.....	27	18	.....	16	13½	Lake silts (?) with basalt fragments.
22	.....	27	18	.....	22	21½	Do.
23	Mr. Lang	27	18	.....	23	22	0–16, lake silts (?); 16–23, basalt fragments.
24	J. A. Pond	27	18	21	20	20	Alluvium and lake silts.
25	John Ross	27	18	7	21	19½	Lake silts.
26	Mr. Anderson	27	17	.....	27	20	Do.
27	(Auger hole)	27	17	.....	20	17	Sandy clay.
28	....do	27	17	.....	20	.....	Sands and moist clays.
29	....do	26	17	.....	19½	.....	0–19, sands and moist clay; 19–19½, tuff.
30	....do	26	16	.....	16	13	Moist clay (at edge of alkaline pool, Pl. III, *C*).
31	....do	26	16	.....	3	Dry.	Loose tuffaceous soil (?).
32	....do	26	15	.....	7½	Dry.	0–6½, silt and sand; 6½–7½, tuff.
33	....do	26	15	.....	16	12	Silts, sands, and clays; 8–9, moist sand containing fresh-water shells.
34	....do	25	14	.....	4	Dry.	Loose soil, from decomposed tuff.
35	(Well)	25	14	.....	26	25	0–25, lake silts; 25–26, tuff.
36	(Auger hole)	27	17	.....	26	24	Silts, sands, and clays.
37	....do	27	17	.....	7	Dry.	0–6, silts and sand; 6–7, tuff.
38	....do	27	17	.....	5	Dry.	0–4, lake silts; 4–5, tuff.
39	....do	28	16	.....	24	24	0–16, lake silts and clays; 16–24, moist clay.
40	....do	28	16	.....	5	Dry.	0–4, lake silts; 4–5, tuff.
41	....do	28	16	.....	4	Dry.	0–3, lake silts; 3–4, tuff.
42	(Well)	28	16	.....	15	Dry.	Lake silts.
43	F. M. Chrisman	28	14	.....	247	49	0–108, lake silts and sands; 108–223, tuff; 223–247, basalt (?).
44	Roy Ward	28	14	.....	90	Dry.	Lake silts (?).
45	T. J. La Brie	28	14	.....	15	10	Lake silts (near edge of marsh).
46	Hayes Bros.	27	14	.....	10	5	Do.

[a] Locations indicated by corresponding numbers on fig. 1, p. 60.

Throughout the settled area the soil is composed of sands and sediments, which extend to a considerable depth. No coarse gravels are met. The sink of Peter Creek, which at first glance seems to be a separate valley, is really connected with the main valley by a broad drainage channel to the east of Bunchgrass Butte, and the same fine sediments are found in it as in the main part of the valley. In four of the five wells examined in the sink the water level is 20 to 25 feet below the surface, and the water is of good quality, the electrolytic bridge[a] indicating an alkaline content of 30 to 40 parts in 100,000. The fifth well is in the southwest end of the so-called sink, near the

[a] See footnote on p. 13.

basalt rim. It has been dug 25 feet deep, passing through the usual silts at a depth of about 18 feet, and penetrating the remainder of the distance into decomposed basalt, without finding water.

Several wells along the northern side of "Sucker Flat" have also reached the basalt at depths of 10 or 12 feet. A small amount of water of fair quality has been found at this depth. Well No. 9 also reaches basalt at a depth of 11 feet, but its water is much more alkaline than that of the others. Half a mile north of this well basalt has been found only 2 or 3 feet below the surface, although there is no indication in the character of the brush that the soil here is so shallow. As shown by the wells farther south in the flat, the soil in that part is deeper. Basalt has not been found in them at a maximum depth of 31 feet in well No. 19. The ground-water level varies from about 10 feet below the surface near Cliff post-office to 25 feet near Christmas Lake. The material in which water is found varies in texture from sandy to clayey.

South and west of Christmas Lake the waters are as a rule of better quality than in the area near Fossil Lake. In October, 1906, the water level was about 20 feet below the surface and the mineral content was from 25 to 50 parts in 100,000. In all of the wells it has been noticed that on standing for any length of time the water becomes more strongly alkaline and has an odor as of decaying organic matter. In one well, near No. 15, even though in constant use, the water became so strong as to necessitate the digging of another well.

The wells on the south side of the valley show that the sediments thin out there as on the north. Fragmental volcanic material is met near the bottoms of wells Nos. 21, 22, and 23, which, being from 16 to 23 feet deep, are extended only a foot or so below the water level.

West and northwest of Sevenmile Ridge a number of auger holes were put down, which indicate that the tuff exposed in this ridge, in the hills near Table Rock and in Fort Rock, underlies this part of the valley at shallow depths. Some irregularities in its surface have perhaps formed basins, as at test holes Nos. 33 and 39, where water was found at depths of 12 and 24 feet, respectively; but in others a hard material, probably the tuff, was encountered at 3 to 20 feet below the surface.

A short distance south of Fort Rock a well 25 feet deep has been dug, which passes through 25 feet of the usual light-colored silts into the tuff. The water was 1 foot deep in October, 1906, and although it evidently had been standing a long time, contained only 40 to 50 parts of solids in 100,000.

There were no wells in the southeast arm of the valley and no test holes were sunk in it, but Mr. A. W. Long, of Lake, reports having found water at a depth of 15 feet at one point in this area. Its general character indicates water conditions similar to those near Fossil Lake rather than to those of the western part of the valley.

ANALYSES OF WATERS.

Analyses of three well waters of this valley were made, those of James Wilson (well No. 12), J. C. Green (well No. 14), and John Ross (well No. 25). These are given in Table C, on page 72 (samples C, D, and E), and show alkaline contents, respectively, of 36.8, 235, and 432.8 parts in 100,000. There is no change in the character of the surface to indicate why the water at Mr. Wilson's should be so much purer than that at Mr. Green's, except that the former is nearer the edge of the valley. In digging Mr. Ross's well a lump of gypsum (sulphate of lime) a foot long and 6 or 8 inches in diameter was found at a depth of 14 or 15 feet (water being struck at 19½ feet); this makes the high percentage of sulphate in this water not surprising. Its mineral character is distinctly appreciable to the taste.

SPRINGS.

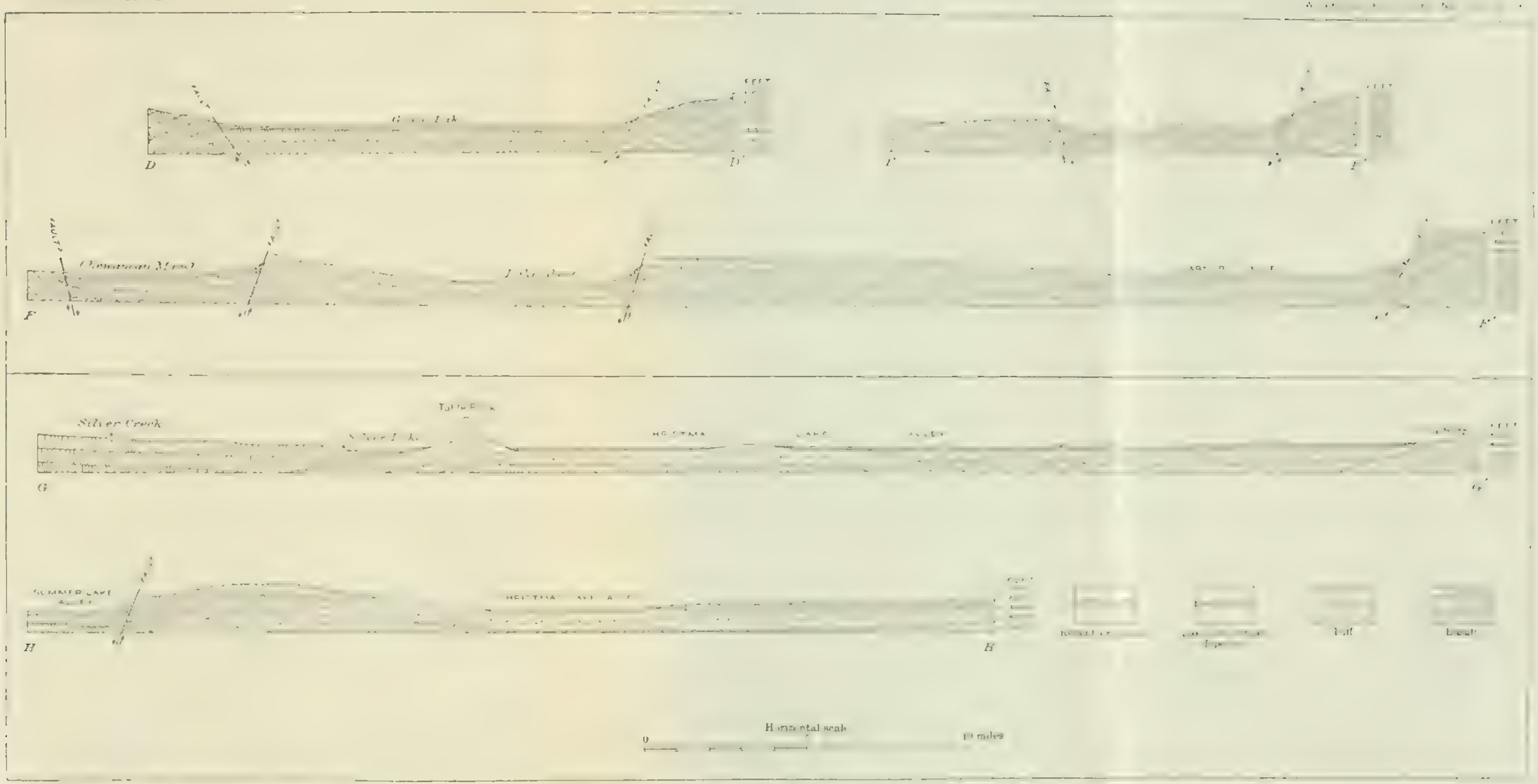
Close to the western shore of Christmas Lake there is a well 9 feet deep, in which the water stands about 5 feet below the surface. Its temperature in October, 1906, was 62° F., both on cold mornings and at midday. Its mineral content is about 40 parts in 100,000. It is said that originally there was a spring here, but that when the willows and nearby sage were cleared off it was soon buried by sand and was reopened only by digging this well.

Christmas Lake is fed by an intermittent spring at its south end. Fossil Lake is also said to be fed by a spring near its center, from which, it is claimed, range riders have drunk when the lake was dry.

The most interesting springs in the valley are those known as Mound Spring and Sand Springs. These rise in the sands of the area east of Fossil Lake, forming valued watering places for stock. Mound Spring is the larger, having a flow of about 2 miner's inches in October, 1906, which supplied a pond 75 yards across. The water is sulphurous in taste and rises with a temperature of 62° F. Sand Springs, one-third mile northward, are no doubt of the same origin, but the flow is less, being, as nearly as could be measured, about 1½ inches. The nearness of these springs to the sand dunes is shown in Pl. IX, *C*.

DEEPER ALLUVIAL WATER.

It has been stated in preceding pages that wells along the edges of the valley show that basalt there underlies the sediments at shallow depths. The low dips of the beds in the surrounding basalts, and a basaltic ridge that extends southward from Bunchgrass Butte, indicate that the lake sediments are not very deep at any point in the valley, nor do extensive alluvial slopes exist along its sides. So, while a larger supply of better water than that of the present shallow wells may be found deeper below the surface, it does not seem probable that flowing wells can be developed in the lake sediments of this valley.



APPROXIMATE GEOLOGIC SECTIONS ALONG LINES SHOWN ON PLATE

ROCK WATER.

Structural conditions.—The structural conditions affecting the existence of flowing artesian water in the rocks underlying this valley may be stated briefly as follows: All along the valley's southern border the lava sheets dip uniformly toward the valley at low angles; on the eastern side also the slope is gentle toward the valley. The structure to the north is largely obscured by the recent lava flows, but the older beds appear to be nearly horizontal; as exposed where they form the slopes to the sink of Peter Creek, however, they also appear to dip slightly toward the valley. On the west the Conley Hills and the eastward-dipping tuff ridge near Table Rock probably separate Christmas Lake Valley structurally from Silver Lake Valley. Within the valley itself there are at least two irregularities in the shallow basinlike structure. From Bunchgrass Butte a low basalt ridge extends southward toward the projecting scarp on the opposite side of the valley, and in Sevenmile Ridge there is a similar low peninsulalike ridge, but of tuff, pointing toward isolated blocks of the same material on the north side of the valley. In the tentative sections (Pl. X) the structure as interpreted is shown.

From these features it appears that in addition to the general low synclinal structure of the valley as a whole there is also a tendency toward folding along axes trending north and south. If this interpretation is correct the valley is divided into three shallow basins, the eastern basin being that of Fossil Lake, the central that of Christmas Lake, and the third the desert west and northwest of Sevenmile Ridge.

Favorable indications.—These minor secondary folds probably do not affect the likelihood of the existence of artesian water, for they are slight, and tend only to divide the valley, not to prevent the percolation toward it of deep water. The valley as a whole is a structural trough, and therefore the chances of obtaining deep water under pressure seem favorable. The absence of extensive faulting is also a condition which is favorable to the presence of rock water under pressure and which was not found in the southern valleys.

As before stated, the temperature of Mound Spring is 62°, while the mean annual temperature of the valley is about 44°. Assuming the usual increase of temperature with depth as 1° F. for each 50 feet, the water of this spring probably rises from a depth of 900 feet.

The presence of this warm spring, and possibly also the same temperature of the well at Christmas Lake, must be taken as indicating that deep water under pressure does exist under this valley.

In the Connell-Ritzville district, in east-central Washington,[a] water is obtained at an average depth of 325 to 400 feet, in decomposed or

[a] Calkins, F. C., Geology and water resources of a portion of east-central Washington: Water-Sup. Paper No. 118, U. S. Geol. Survey, 1905, pp. 69-75.

fragmental basalt. None of the wells have been cased, but in several artesian pressure causes the water to rise a considerable height above the level at which it is struck, and it probably would rise to the surface if properly tapped. This is in a very gently sloping area, the dip of the beds being hardly appreciable to the eye. It is thought that the water of the district must come from a long distance, from the higher northwestern country, to attain the pressure that it has. Such a condition exists on a larger scale in the northern Mississippi Valley, where the surface exposure of the water-bearing Dakota sandstone is found many miles from the artesian localities.

The Pauline Mountains lie about 30 miles north of Christmas Lake Valley. About the same distance west of Silver Lake Valley is the Walker Range, an eastern spur of the Cascades. Neither of these ranges was visited, but they are thought to consist of the same series of basalts that cover most of Lake County, and it seems not improbable that the rocks dip from them toward Christmas Lake and Silver Lake valleys, and that an underground water supply such as exists in central Washington may reach these valleys from those sources.

On the whole, while the data concerning the underground conditions within these two valleys are meager, the indications in favor of the existence of deep waters are sufficient to warrant the sinking of test wells. This matter has been seriously considered, especially since the settlement of Christmas Lake Valley. During the fall of 1906 it seemed about to assume definite shape, and it is hoped that work on a deep boring will soon be begun.

ALKALI LAKE VALLEY.

One other valley, that of Alkali Lake (Pl. VII, *B*, p. 26), in the northeastern part of the county, was examined in some detail. This valley is about 20 miles long from north to south and about one-fourth as wide, being partially divided into two basins by the spur of hills north of the playa known as Alkali Lake. In each of the basins the surface is nearly level, its chief irregularities being the sand ridges or the hillocks of fine silts previously described. The area around the lake is for the most part a greasewood flat, in which the alkali is very evident; during storms the soil becomes a slippery mud that, on drying, is caked by the soda salts to a hardpan surface. In North Alkali there is some better looking land, but it is rather "spotty," being in some places loose and sandy, with a good growth of sage, and in other places a hard, fine silt with but a scanty covering of greasewood.

On the east the basin is bordered by a scarp which is 1,200 feet in height in its southern portion, but which dies out toward the upper end of the depression. In other directions the basalt slopes rise gently to the higher desert plateau.

Through Venator Canyon on the northeast and a gorge at the northern end gravels have been brought down from the slopes of Little Juniper Mountain, and in the northwestern arm of the valley flood waters have deposited coarse sands and gravels, but elsewhere only fine sands and sediments are to be seen.

The only house in this valley is on the west edge of Alkali Lake. It is a usual stopping place for travelers and range riders, and although permanently occupied by tenants who care for stock on the surrounding range, no attempt has been made at agriculture, for the soil is too alkaline.

In the looser soil at the north end of North Alkali Valley a few acres were cleared by a prospective settler, and grain raised; but attempts to get water failed, several wells reaching basalt at shallow depths, and the claim has been abandoned.

The only spring of importance in this valley is that at the west edge of Alkali Lake, at the only ranch house in the valley, and it has long been known as the only watering place within a radius of 20 miles. It is said that in early days the pool where this spring rises was only 3 or 4 feet in diameter, but of great depth, and that range riders in attempting to sound it let down a weight several hundred feet without reaching botton. This is the usual legend about desert springs of this character and probably has no foundation in fact. Several years ago a levee was built around the spring to raise its water level and obtain better run-off to the lake, and a pond about 15 yards in diameter was thus formed. In this a weight could be lowered only 15 feet. The temperature of the water in this pond (59°), which is probably less than when it first rises, indicates that it is of deep origin, however; according to previously used assumptions, it comes from a depth of 700 to 800 feet. Small fish live in the pool. In October, 1906, this spring discharged from 2 to 2½ miner's inches, which is its average summer flow, but during the winter its yield is said to be somewhat greater. The water has been reported to contain borax, but although it was not tested for borates, the analysis (sample A, p. 72) shows it to contain only 28 parts of solid matter in 100,000 parts of water, all of which is accounted for in the salts determined.

In North Alkali Valley there is a playa whose surface is about 12 feet below the mean level of the basin. This depression is probably a "blow-out" that has been carved in the lake sediments by wind erosion. Along its northern side, during the spring and early summer, seepage springs furnish water for the range cattle, but they dry up later in the season. Similar springs appear along the northern edge of Alkali Lake after storms and sometimes during periods of cool, cloudy weather. The fluctuation of these springs is of interest in showing the summer lowering of the ground-water level and its

changes due to weather conditions, as well as in indicating a seepage flow southward toward the lake, as would be expected.

Several auger holes that were put down in the valley filling in North Alkali Valley to a depth of 18 or 20 feet show it to be composed of fine silts interbedded with sands, as in Christmas Lake Valley; the water level in November, 1906, was about 15 feet below the surface.

As in the other valleys, water of better quality than that near the surface probably is present near the bottom of the sediments in this basin. But the evidence of extensive faulting along the eastern side of the depression, as at Abert Lake, indicates that deep rock water under artesian head does not underlie this region, and therefore, even if the land were not for the most part too alkaline for agriculture, cheap water for the necessary irrigation would not be available. Hence it seems improbable that more than a few scattered homes can ever be established here.

RECLAMATION PROJECTS.

One-third of the entire area of the United States (exclusive of Alaska and outlying territories) is still vacant public land. But nearly all of this that is susceptible of being tilled lies within the arid regions, or those having an average annual rainfall of less than 20 inches; and there are now in these regions few localities where homes can be easily made, owing to the great cost of developing water. It is for this reason that the Reclamation Service has been established, to aid in settling and rendering productive the great arid tracts, by constructing dams, reservoirs, and canals to supply the needful water for irrigation.[a]

Much of the valley land of Lake County was temporarily withdrawn from entry a year or more ago, pending the examination of the Silver Lake, Chewaucan, and Ana River reclamation projects. Part of the

[a] The following extracts from the reclamation law, approved June 17, 1902, contain its main terms and provisions:

"SEC. 1. * * * All moneys received from the sale and disposal of public lands in Arizona, California, Colorado, Idaho, Kansas, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oklahoma, Oregon, South Dakota, Utah, Washington, and Wyoming * * * shall be * * * appropriated as a special fund in the Treasury to be known as the 'reclamation fund' to be used in the examination and survey for and the construction and maintenance of irrigation works for the storage, diversion, and development of waters for the reclamation of arid and semiarid lands in the said States and Territories. * * *."

"SEC. 3. That the Secretary of the Interior shall * * * withdraw from public entry the lands required for any irrigation works contemplated under the provisions of this act, and shall restore to public entry any of the lands so withdrawn when, in his judgment, such lands are not required for the purposes of this act; and the Secretary of the Interior is hereby authorized, at or immediately prior to the time of beginning the surveys for any contemplated irrigation works, to withdraw from entry, except under the homestead laws, any public lands believed to be susceptible of irrigation from said works; * * * that public lands which it is proposed to irrigate by means of any contemplated works shall be subject to entry only under the provisions of the homestead laws in tracts of not less than forty nor more than one hundred and sixty acres, and shall be subject to the limitations, charges, terms, and conditions herein provided: *Provided*, That the commutation provisions of the homestead laws shall not apply to entries made under this act.

"SEC. 4. That upon the determination by the Secretary of the Interior that any irrigation project is practicable, he may cause to be let contracts for the construction of the same * * * and * * *

land in Christmas Lake Valley was again restored and opened to entry in September, 1906, but the greater part of the vacant land susceptible of irrigation under these three projects is still withdrawn. These projects are necessarily only tentative, and until several years' measurements of the streams indicate the supply of water that can be depended upon no further action can be taken.

Here, as elsewhere, the Government has taken an important preliminary step toward conserving the water supply by creating the Goose Lake and Fremont forest reserves, for (with the possible exception of Ana River) all the streams are fed from the wooded mountain slopes, where protection and conservation of the scanty supply of moisture is of the utmost importance to any proposed irrigation project.

Under the provisions of the Carey Act[a] the construction of a reservoir on the upper Chewaucan River and irrigation of much of the lower land has been considered, but nothing has yet been done.

SOILS.

ANALYSES.

Samples of the soil and water were collected at several places in the county and were analyzed by Mr. W. H. Heileman, engineer of soils at Berkeley, Cal.

The soils were taken from near the surface of the uncultivated lands, which at the time the samples were collected (in October) probably contained their maximum amount of alkaline salts, so they are not fair samples. They were taken thus on the assumption that after the dry summer months the soil near the surface would be the most alkaline and would indicate the extreme conditions to be met. It is to be regretted, however, that samples of the deeper soil were not obtained, in order that the question whether there is a great quantity of salts present and danger of their rising with irrigation and cultivation, might have been answered.

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shall give public notice of the lands irrigable under such project, and limit of area per entry, which limit shall represent the acreage which, in the opinion of the Secretary, may be reasonably required for the support of a family upon the lands in question; also of the charges which shall be made per acre upon the said entries, and upon lands in private ownership which may be irrigated by the waters of the said irrigation project, and the number of annual installments, not exceeding ten, in which such charges shall be paid and the time when such payments shall commence. The said charges shall be determined with a view of returning to the reclamation fund the estimated cost of construction of the project, and shall be apportioned equitably. * * *

"SEC. 5. That the entryman upon lands to be irrigated by such works shall, in addition to compliance with the homestead laws, reclaim at least one-half of the total irrigable area of his entry for agricultural purposes, and before receiving patent for the lands covered by his entry, shall pay to the Government the charges apportioned against such tract, as provided in section four." * * *

[a] According to the Carey Act of 1894, the United States may grant and patent to any of the arid States or Territories, free of cost, a total area not exceeding 1,000,000 acres which "the State may cause to be irrigated, reclaimed, occupied, and not less than twenty acres of each one hundred and sixty acre tract cultivated by actual settlers, * * * as thoroughly as is required of citizens who may enter under the desert-land law." After filing an approved map of the land and plan of irrigation, the State is authorized to make necessary contracts and induce settlement, but is not authorized to lease the lands or dispose of them in any way except to secure reclamation. A maximum of 160 acres can be held by one person, and the surplus over cost of reclamation, derived from the sale, is to be held as a trust fund to be applied to the reclamation of other lands in the same State.

Following are the results of the soil and water analyses:

TABLE A.—*Alkali content of water extract on surface soils of Lake County, Oreg.*

[Figured as sodium salts. Amounts are percentages. W. H. Heileman, analyst.]

No.	Locality.	Water-soluble salts in soil.	Sodium chloride.	Sodium bicarbonate.	Sodium sulphate.	Sodium carbonate.
1	Thousand Spring Valley	1.12	0.30	0.22	0.59	0.02
2	3 miles west of Christmas Lake	.19	.02	.07	.11	0
3	One-half mile south of Christmas Lake	2.85	.75	.07	2.03	0
4	Well No. 21	.17	.02	.09	.07	0
5	North end of sink of Peter Creek	.18	.03	.08	.07	0
6	1 mile south of Fossil Lake	2.46	.30	.08	2.08	0
7	One-half mile east of Cliff post-office	.09	.01	.05	0	0
8	Center of North Alkali flat	.08	.02	.03	0	0
9	Western arm of Alkali basin	.06	.02	.04	0	0

TABLE B.—*Plant-food analyses of soils represented in Table A.*

[Results are in per cent on air-dry soil. Analysis acid extract; Official Association method. W. H. Heileman, analyst.]

No.	Insoluble residue.	Moisture.	Organic and volatile.	Calcium (CaO).	Phosphoric acid (P_2O_5).	Potash (K_2O).
1	73.45	1.89	6.50	5.65	0.18	1.11
2	77.68	2.79	3.23	1.51	.14	.73
3	66.62	3.61	5.80	5.17	.19	1.01
4	73.22	3.23	4.08	2.51	.05	.51
5	78.67	2.30	5.90	1.88	.11	.30
6	58.07	4.20	10.96	10.70	.38	.56
7	79.14	1.97	3.65	1.41	.13	.54
8	79.24	2.56	4.22	3.16	.12	.51
9	76.85	2.33	4.59	1.06	.11	.56

TABLE C.—*Analyses of waters from southern Oregon.*

[W. H. Heileman, analyst.]

	A.	B.	C.	D.	E.	F.
Total solids *a*	28.00	10.00	36.8	235.00	432.80	22.00
Calcium (Ca)	1.33	1.28	2.24	5.56	8.20	1.18
Magnesium (Mg)	.82	.51	1.70	4.80	8.20	6.10
Sodium and potassium (Na+K)	8.24	1.38	8.35	70.00	128.50	5.48
Sulphate (SO_4)	2.90	.17	2.51	88.00	204.00	1.24
Carbonate (CO_3)	.00	.00	.00	.00	.00	.00
Bicarbonate (HCO_3)	16.66	4.40	25.30	78.80	42.10	11.60
Chlorine (Cl)	3.44	.61	1.97	15.25	57.40	3.94
Nitrate (NO_3)	.00	.00	.00	Trace.	Trace.	.00
Total solids by summation	33.39	8.35	42.07	262.41	450.40	29.54

a In a letter accompanying the above analyses Mr. Heileman states that "Total solids" means total mineral solids "determined by evaporating a known portion of the clear water to dryness and weighing the residue. In an evaporation there is always a loss of certain acid radicles, principally carbonate and bicarbonate, or at least a change in these two radicles. The effect of this is to make the total solids as directly determined lower in parts than is the summary of the analysis. There is good ground for assuming that the difference between total solids and the summary of the analysis is due to a loss in the bicarbonates in the total solids determination."

A. Spring at Alkali Lake.
B. Stream at A. Eglis's, Wagontire Mountain.
C. Well of J. Wilson, near Fossil Lake.
D. Well of J. C. Green, near Fossil Lake.
E. Well of John Ross, Christmas Lake Valley.
F. Springs of Ana River.

The most noticeable facts shown by these analyses are the absence of carbonates in the waters and in all the soils except that of Thousand Spring Valley, and the high sulphate content, to which salt the bicarbonate and chloride are of secondary importance. The three soils having highest sulphate content (samples 1, 3, and 6) are also the highest in chloride, containing percentages of these white alkalis that are considered to be the limit of tolerance for nearly any crop. For ordinary crops this limit is usually placed at 0.05 to 0.10 per cent for the carbonate of soda and 0.25 to 0.50 per cent for the chloride, while nearly 1 per cent of the sulphate may be endured. So it is seen that, with the exception of sample No. 1 (from J. H. Bonham's ranch, in Thousand Spring Valley), which has been found by trial too alkaline for plant growth, and Nos. 3 and 6, which were taken from evidently alkaline areas, the surface soils do not contain enough of the alkalis to be seriously detrimental.

SOIL CONSTITUENTS.

In Hilgard's recent work on soils the effects of the several valuable constituents of the soil, as well as of the alkalies, are fully treated. From his deductions the following extracts are taken: [a]

INSOLUBLE RESIDUE.

About 69 per cent has been found to be the general average of insoluble matter in soils of arid regions throughout the United States. This consists chiefly of free silica (quartz), but the hydrous silicates, forming most of the material known as clays, are also usually included under this head. With this proportion the soils analyzed are seen to agree fairly well.

LIME.

Physically even a small amount of lime carbonate, by its solubility in the carbonated soil water, will act most beneficially in causing the flocculation of clay and in the subsequent conservation of the flocculent or tilth condition by acting as a light cement, holding the soil crumbs together when the capillary water has evaporated, thus favoring the penetration of both water and air and of the roots themselves. * * * Amounts of lime carbonate in excess of 2 per cent do not add to the favorable effects, except as would so much sand.

As to chemical effects, among the most important are—

1. The maintenance of the neutrality of the soil by the neutralization of acids formed by the decay of organic matter or otherwise.

2. The maintenance, in connection with the proper degrees of moisture and warmth, of the conditions of abundant bacterial life, * * * more especially those of nitrification, thus supplying the readily assimilable form of nitrogen; also in favoring the development and activity of the root bacteria of legumes and of the other nitrogen-gathering bacteria, such as *Azotobacter*. * * *

3. The rendering available, directly or indirectly, of relatively small percentages of plant food, notably phosphoric acid and potash. * * *

4. The prompt conversion of vegetable matter into black, neutral humus and (as shown in the case of the soils of the arid region) the concentration of the nitrogen in

[a] Hilgard, E. W., Soils, The Macmillan Company, 1906, p. 379 et seq.

the same, while accelerating the oxidation of the carbon and hydrogen, as shown by S. W. Johnson and others.

* * * * * * *

7. In alkali soils, according to Cameron and May, it counteracts the injurious action of the soluble salts upon the growth of plants, not only in the form of carbonate, but also in those of sulphate and chloride.

An average arid-region soil as given by Mercker, Halle station, Germany,[a] contains 1.36 per cent lime, 0.73 per cent potash, and 0.12 per cent phosphoric acid. For a "good" soil he gives the lime (in a sandy soil) at 0.20 to 0.30 per cent; potash, 0.25 to 0.40 per cent; phosphoric acid, 0.15 to 0.25 per cent; from which it is seen that the arid soils are usually low in phosphoric acid but high in lime and potash.

With these results the soil analyses (Table B, p. 72) are seen to compare fairly well, being (with the exception of No. 6) rather low in phosphoric acid but high in lime. Sample No. 6 contains a very high lime content—too high, in fact, as it may cause marliness and render the soil unfavorable to plant growth unless properly handled.

In general, however, the results of these analyses are satisfactory, showing the soils to be not far different from those of other fertile though arid valleys. They are well supplied with lime, potash, and organic matter, but are rather low in phosphoric acid.

SALTS PRESENT.

Around the lake edges and some playas of the higher lands efflorescent saline crusts form. Ten of these were analyzed to determine the proportion of the several salts present, and the results are given in the following table:

Tests on alkali samples (mostly crusts).

[Results show percentage, figured on material analyzed. W. H. Heileman, analyst.]

No.	Locality.	Sulphates (SO_4). Qualitative only except No. 7.	Carbonates (CO_3).	Bicarbonates (HCO_3).	Chlorine (Cl).	Calculated as sodium salt.		
						Sodium carbonate (Na_2CO_3).	Sodium bicarbonate ($NaHCO_3$).	Sodium chloride (NaCl).
1	East side Summer Lake.	Heavy	14.28	9.93	0.51	25.28	13.50	0.84
2	South end Christmas Lake.	do	6.02	4.65	.38	10.65	6.32	.63
3[b]	West side Alkali Flat.	do	6.74	4.66	6.23	11.93	6.34	10.28
4	Edge of pool in Alkali Flat.	do	14.64	9.07	15.35	25.90	12.33	25.31
5	Center of Alkali Flat.	do	3.74	8.77	.71	6.62	11.92	1.17
6	Eastern pool northwest of Christmas Lake.	Very heavy	.60	.13	2.25	1.06	.18	3.71
7	Western pool northwest of Christmas Lake.	do						
8	Efflorescence in "Sucker Flat."	Heavy	.18	.30	1.67	.32	.41	2.75
9	Playa in North Alkali	do	8.07	6.43	5.15	14.28	8.74	8.50
10	North end Lake Albert.	do	22.40	10.24	1.54	39.65	13.92	2.54

[a] Hilgard, Soils, p. 369.
[b] An acid extract showed heavy lime-carbonate content.
[c] Practically pure sodium sulphate (99 + per cent).

From these analyses it is seen that the sulphate of soda (Glauber's salt) is the most abundant in all these deposits, as it is in the soils themselves.

The crust that forms over the playa of Alkali Lake is occasionally used as stock salt. As before stated, borax claims have been located in this flat, but analysis of the material shows it to consist, as elsewhere, of the sulphate, carbonates, and chloride of soda; there can be but little borax (biborate of soda) in this deposit.

The pools about 10 miles northwest of Christmas Lake, from which samples Nos. 6 and 7 were obtained, are shown in Pl. III, *C* (p. 10). The salt, No. 7, is also used for stock, but sometimes with injurious effects on the animals; nor is this to be wondered at, when analysis shows it to be nearly pure Glauber's salt.

ALKALINE SOILS.

The proper treatment of alkaline soils and the methods of farming in arid regions are treated in several bulletins of the Department of Agriculture,[a] but a short discussion of the subject may not be out of place here.

THE ALKALIES AND THEIR EFFECTS.

The three chief salts known as alkali are the chloride, sulphate, and carbonate of soda, called respectively common salt, Glauber's salt, and sal soda. The two former are the white alkalies, while the latter is known as black alkali, since it turns organic matter with which it comes into contact brown or black. Borax also sometimes occurs as an alkali, but it is by no means as common as the others. The nitrate and phosphate of soda and the sulphate of potash also occur in nearly all soils, but as nutritive salts, essential to plant life, not as injurious ones.

Plants vary greatly in the amount of alkali they will endure. Members of the Goosefoot family, which includes the saltbushes and beets, will stand much of all three salts, while the legumes (peas and beans) resent small amounts of either. Common salt and Glauber's salt are by no means as harmful as the black alkali. In general—

* * * when present in soils to the exclusion of other salts, 0.05 per cent of sodium carbonate represents about the upper limit of concentration for common crops. One-half of 1 per cent of sodium chloride is commonly regarded as the endurance limit of crops, and 1 per cent of sodium sulphate. Sodium sulphate, then, is the least injurious and sodium carbonate the most injurious of the salts usually constituting the greater part of alkali under ordinary field conditions, while sodium chloride occupies a middle position.[b]

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[a] The following Farmers' Bulletins treat of subjects of especial interest to those living in the arid regions: No. 52, The Sugar Beet, 48 pp.; No. 77, The Liming of Soils, 24 pp.; No. 88, Alkali Lands, 23 pp.; No. 108, Saltbushes, 20 pp.; No. 139, Emmer: A Grain for the Semiarid Regions, 16 pp.; No. 215, Alfalfa Growing, 40 pp.; No. 266, Management of Soils to Conserve Moisture, 30 pp. These may be obtained free on application to the Secretary of Agriculture, Washington, D. C.

[b] Dorsey, Clarence W., Reclamation of alkali soils: Bull. No. 34, Bureau of Soils, U. S. Dept. Agriculture, 1906, p. 10.

The chloride and sulphate seem to act largely by their presence in excess in the sap, reducing the vitality of the plant. The carbonate, attacking the bark of stalks and roots just beneath the surface, blackens it and makes it spongy, virtually girdling the tree or plant. This salt also has the property of puddling the soil when much moisture is present, and forms a hardpan surface.

The effect on plant life of the bicarbonates, which are also present in considerable amount, is but little understood, but it is not in general considered to be detrimental.

Analyses of soils made by Heileman both before and after prolonged irrigation indicate that by flooding methods of irrigation the bicarbonates are to some extent changed to carbonates, seeming to show that the carbonate salts are at all times unstable.

Hilgard [a] also states that when irrigation ditches in sandy land saturate the soil, thus raising the water table and bringing close to the surface the entire mass of alkali salts and keeping them there for some time, "alkali salts originally 'white' will by chemical change become 'black' by the formation of carbonate of soda from the Glauber's salt, greatly aggravating the injury to vegetation."

TREATMENT OF ALKALINE SOILS.

In regions of slight rainfall it is of particular importance that as much of the moisture as possible be kept in the ground, near the surface, where it can best be taken up by plants. The prevention of evaporation is the chief object in this endeavor, and is partially accomplished by shading the ground, as in the case of alfalfa and similar crops that furnish their own shade, by mulching with straw, or by frequent cultivation to keep the upper few inches of soil in a light, porous condition, so as to prevent further rise of moisture to the surface.

In arid lands brought under irrigation the increased evaporation often greatly accelerates the slower natural action of the ground waters in bringing to the surface and depositing soluble salts on evaporation, and regions formerly not alkaline, as the Yellowstone Valley near Billings,[b] may become so by excessive irrigation.

Leaching down and washing out of the soil by thorough irrigation, where there is good underdrainage, is the best way of getting rid of these salts; but if the drainage is poor, the application of a minimum amount of water and cultivation to prevent its rise and evaporation is practiced to keep the salts down below the plant roots. For shallow-rooted crops, as the cereals, deep plowing, to turn the alkaline surface soil under, is also often of great benefit.

[a] Hilgard, E. W., Nature, value, and utilization of alkali lands: Bull. No. 128, College of Agriculture, Univ. California, 1900, p. 6.

[b] Whitney, Milton, and Means, Thomas H., The alkali soils of the Yellowstone Valley: Bull. No. 14, Division of Soils, U. S. Dept. Agriculture, 1898.

The chloride and sulphate can not be neutralized, but by the application of gypsum (land plaster) the carbonate may be changed to the comparatively harmless sulphate.

Theoretically the amount of gypsum to be applied should be one-third more in weight than the amount of soda in the land, but owing to impurities in the commercial material about twice the theoretical amount is necessary to neutralize all of the soda. It is not necessary to apply it all at once, but this should be done when rains or irrigation will carry the gypsum down and bring it into contact with the sodium carbonate. The gypsum also changes any borax that may be present to the harmless borate of lime. Two hundred pounds to the acre is an ordinary treatment, the effect being noticeable in two or three days by the disappearance of the discolored spots.

If in any of the valleys of Lake County it should be found desirable to use gypsum on parts of the land, it can probably be best obtained at Lime, on the eastern border of the State, where there is a deposit of good quality, as yet but little exploited.

Almost all of the alkaline salts are contained in the upper 4 or 5 feet of soil, and in level unirrigated lands they are often concentrated in the second or third foot. The amount of alkaline salts in a region is thus limited, and, aside from underdraining, may often be directly removed by collecting the crust by sweeping or with scrapers, and sometimes by planting and harvesting varieties of salt bush. Some of these take up nearly one-fifth of their dry weight of salts (mostly common salt), and hence materially reduce the alkaline content of the land.

CONDITIONS IN LAKE COUNTY.

It has been shown that throughout the valley lands of Lake County the chief alkali is the sulphate. The excess of lime in the soil, as has been stated, will to some extent compensate this, and with proper care in irrigating and plowing, it should not cause serious trouble. Neither are troubles from excessive irrigation and rise of the ground-water level apt to be serious in the valleys of Lake County, because of the fairly low present water level and the improbability of development of water to such an extent that it will be used lavishly. From the beginning, however, rather careful irrigation and cultivation immediately afterwards, is advisable, as the salts are much more easily kept down than gotten rid of when they have collected in serious amount.

The high productiveness of the arid lands when brought under cultivation, and the noxious salts removed or kept down, makes them valuable and well worth reclaiming; hence they are receiving more and more attention as other vacant lands become scarcer.

CROPS ADAPTABLE TO ALKALINE SOILS.

Alfalfa when well started will stand a considerable amount of alkali, but the seed is extremely sensitive to black alkali, and is often killed before germination unless gypsum is used in sowing. Sugar beets are also adaptable to alkaline lands. Glauber's salt little affects their sugar-making quality, and a relatively large amount of common salt is required to render them unfit for this purpose. The cereals wheat, rye, and barley also resist moderate amounts of alkali. Root plants, however, such as potatoes, do not do well as a rule, tending to become watery when grown in alkaline ground.

Of fruits, there are few that will grow on the desert tracts where alkali, drought, and frost must to a greater or less extent be endured; but of those suitable to regions subject to frosts grapes, pears, and apples will stand the greatest amount of alkali. Of other trees, for shade or wood, the conifers (pines, firs, cedars, etc.) are very sensitive to black alkali and will not endure much white alkali, hence they are usually debarred from the lower valleys of arid regions. Cottonwoods will grow where water is near the surface, but they can not withstand drought. Other trees, as the red gum, which will withstand strong alkali, are susceptible to frost. Thus it is that, although pines, junipers, and cottonwoods are found along the margins, they do not grow native in the main parts of such valleys, which are given over to sage and salt bushes.

COST OF DEEP WELLS.

As few deep wells have been sunk in southern Oregon, there is among the settlers no definite idea of what such a well may cost. Figures showing the cost in other localities are therefore here introduced to indicate what may be expected in this matter.

In unconsolidated alluvial materials wells are often bored to depths of 50 feet or more, and up to 3 feet in diameter, with forms of the earth auger or lipped bucket. Such an outfit was used successfully in Christmas Lake Valley in the summer and fall of 1906 to put down several wells. This method, of course, can not be used in compacted or coarse material.

In deeper gravels and sands the California or "stovepipe" method is extensively used. In this method short sections of riveted steel pipe from 8 to 14 inches or more in diameter are sunk by hydraulic jacks, sometimes to a depth of more than 1,000 feet. The material within the casing is removed with a sand bucket or sand pump as the sinking proceeds, and the casing is perforated at water-bearing strata by a heavy cutting knife. This method is much used in southern California and in San Joaquin Valley in central California.

The following tables, taken from Water-Supply Paper No. 137 of the United States Geological Survey, indicate the usual costs of such wells near Santa Ana, Cal.:

Cost, per foot, of drilling wells.

	4-inch.	5-inch.	6-inch.	7-inch.	8-inch.	9½-inch.	10-inch.
First 100 feet	$0.30	$0.30	$0.35–.40	$0.40	$0.40–.50	$0.60–.65	$0.65
Additional for each 50-foot increase	.25	.25	.20–.30	.20–.35	.20–.35	.20–.35	.35

Following is the general price per foot of riveted steel casing made up into 2-foot joints of the sizes and gages generally used. The price varies, of course, with the steel market.

Cost of well casing.

Diameter in inches	Gage.	Price per foot.	Diameter in inches.	Gage.	Price per foot.
4	16	$0.32	8	16	$0.55
4	14	.38	8	14	.64
5	16	.35	8	12	.78
5	14	.33	9½	16	.65
6	16	.32	9½	14	.75
6	14	.50	9½	12	.94
7	16	.48	10	16	.68
7	14	.55	10	14	.78

It should be remembered that these prices are for the material near centers of population; in a region like southern Oregon, therefore, the freight would make the cost considerably greater.

The hydraulic method has been successfully used in fine sediments where other methods have failed. A powerful jet of water just below the casing loosens the material and carries it upward out of the hole, so that by adding joints at the top the string of casing is rapidly sunk into the silts. Often a 4-inch well can be sunk to a depth of 400 or 500 feet, cleaned out, and perforated in a couple of days. These wells are usually sunk by contract, cased and ready for use, for about $1 a foot.

For penetrating rock, however, the oil rig, using a heavy drill bit alternately raised and dropped, is the only practical well-drilling outfit. The following costs of drilling in other localities are given to show what may be expected in Lake County if deep drilling is attempted. In southeastern Washington the following prices rule:[a]

The charges for well drilling in the southern part of the wheat lands [of Washington] are as follows: In soil, gravel, etc., above basalt, 50 cents a foot; in rock (which is generally in great part massive basalt, though other varieties after the first basalt is struck are not differentiated), $2.25 per foot for the first 300 feet, and 50 cents per foot

[a] Calkins, F. C., Geology and water resources of a portion of east-central Washington: Water-Supply Paper No. 118, U. S. Geol. Survey, 1905, p. 60.

additional for each 100 feet below that depth. Water for the engine, coal, and board for the outfit are furnished by the owner of the ranch.

In the vicinity of Ritzville [Washington] the terms are slightly higher. For the first 300 feet there the charge is $2.50, and 50 cents higher for each additional 50 feet. On these terms, however, the driller furnishes coal, the cost of which is estimated at about 25 cents for each foot drilled in basalt. In all cases water is guaranteed, and the risk of losing tools (which generally also necessitates abandoning the hole) is borne by the driller. The average cost of a well at these rates is probably not far from $800, though it reaches a maximum of over $2,000.

"Stovepipe" wells can probably be sunk with success in Summer Lake and Goose Lake valleys, and possibly also in those of Silver and Christmas lakes. But in the latter two, if drilling for deep water be attempted, the country rock, basalt, will be met beneath the sediments, and will probably have to be penetrated some distance before rock water, if such occurs, is struck. The idea, to some extent prevalent, that water will be found "if one only goes deep enough" is a fallacy; and if the bottom of the basaltic series should be reached and more siliceous rock encountered, like the rhyolite of Gray Butte or of Horning Bend, work might as well be stopped, for there is little hope of striking water-bearing strata in such rock. It is improbable, however, that such material will be encountered in these valleys at depths to which drilling is apt to be carried.

SUMMARY.

The reclamation of the fertile lands in eastern Oregon will depend on the available supply of water, for, as President Roosevelt said in his first message to Congress in 1901, "In the arid region it is water, not land, which measures production." On this account there will probably always remain some fertile land, as in the southwestern part of the United States, irreclaimable for lack of water. While in some parts of the arid regions dry farming of grain is carried on with more or less success, it is improbable that it can profitably be followed in the valleys that have been under discussion.

The supply of surface (stream) water available for irrigation in Lake County is fairly well known, and should it be developed it will by no means be sufficient to irrigate all of the arable land. The underground supply is as yet unknown, but on the whole, as has been shown, the indications seem favorable to the development of such water in the valleys of Silver, Christmas, and Summer lakes at least.

The reclamation of these valleys will not only increase the agricultural wealth of the State, but its stock-raising interests will also be greatly benefited. In severe winters the supply of wild hay from the marshes is very inadequate, and many head of stock perish every year from hunger and exposure.

Grain, alfalfa, and sugar beets promise to be the chief crops in the valleys, and it seems that for several years to come nearly all produce will find a home market. The rocky high deserts will probably never be fit for other than grazing purposes, but if feed can be raised in the valleys, to carry greater numbers of sheep and cattle through the severe weather, the winter losses will be decreased and many more head of stock can be ranged in the country. The scarcity of water on the high deserts during the summer (when it is sometimes 30 miles between water holes) will remain a drawback to the grazing of cattle and sheep over these areas during this season. In other regions, as in Texas, wells have been sunk at intervals of 8 or 10 miles, and windmills and troughs supply this deficiency. But until tests have first been made in the more favorable localities, it can not be said whether it is possible or feasible thus to supply water on the Oregon plateaus.

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RECONNAISSANCE TOPOGRAPHIC MAP OF SOUTH CENTRAL OREGON

RECONNAISSANCE GEOLOGIC MAP OF SOUTH CENTRAL OREGON

BY G. A. WARING.

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

WATER-SUPPLY PAPER 221

GEOLOGY AND WATER RESOURCES

OF THE

GREAT FALLS REGION

MONTANA

BY

CASSIUS A. FISHER

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GEOLOGY AND WATER RESOURCES OF THE GREAT FALLS REGION, MONTANA.

By Cassius A. Fisher.

INTRODUCTION.

This report is based on field work done during the season of 1906 in connection with a detailed investigation of the geology and coal resources of the Great Falls coal field. It is designed mainly to furnish information regarding the general geology of the region and the prospects for underground water. A brief description of the different geologic formations is given, with statements concerning their structure, general distribution, and water capacity. The surface waters are also described, including their present and proposed uses for irrigation, water power, etc., and the agricultural interests of different parts of the district are briefly discussed.

The region considered comprises that portion of the Great Plains bordering the Rocky Mountain Front Range, which extends from about longitude 110° W. to about 112° 30′ W., and from about latitude 47° N. to about 48° N. It includes the lowlands lying between the Little Belt and Highwood mountains, and extends to the west and north with increasing width to a point about 10 miles north of Teton River. The area comprises about 3,600 square miles, the location of which is shown in the key map in Pl. I (pocket). It is situated in north-central Montana, mainly in Cascade and Teton counties, but includes portions of Fergus, Chouteau, and Lewis and Clark counties. It is bounded on the south and west by the Little Belt, Big Belt, and Lewis mountain ranges, and on the east and north by the Great Plains and Highwood Mountains.

The topographic map used as a base for the geologic map, and also for the water-resources and other maps presented in the report, was, for the eastern part of the district, taken mainly from detailed reconnaissance surveys of the Great Falls coal field, made from a land-subdivision standpoint by the author and his party. Topographic data for the marginal portions of the east half of the map

were also taken from atlas sheets of the Fort Benton and Great Falls quadrangles surveyed in 1896. The map of the western portion of the field was made in greater part from rapid reconnaissance surveys carried on while the underground-water investigation was being made.

Throughout the work valuable assistance was rendered by W. R. Calvert and D. E. Winchester. These gentlemen mapped portions of the area, collected much of the well and spring data, and made field assays of the water. In the areal geologic mapping assistance was given by H. M. Eakin, who measured numerous sections and collected structural data. Much valuable information was furnished by S. B. Robbins, engineer of the Sun River reclamation project, regarding both underground and surface waters of the Great Falls region, and aid was also given by O. C. Mortson and John French.

LITERATURE.

GENERAL STATEMENTS.

Previous observers have given but little information regarding the underground water resources of the Great Falls region. The surface waters, particularly the Great Falls of Missouri River and the Giant Springs, are phenomena that have attracted widespread attention since the earliest explorers followed up the course of Missouri River to the westward. Captain Lewis, of the Lewis and Clark expedition, who visited this region in 1804, was the first to give an accurate account of the Great Falls and Giant Springs, and doubtless other early explorers had been attracted by them and made brief mention of their occurrence in describing the Northwest Territory. The work of the geologists of the Hayden and transcontinental surveys was confined mainly to the region lying east of Great Falls, and with one or two exceptions did not extend into this district. With the development of water power at the Black Eagle Falls, which took place in 1893, a number of articles appeared in the engineering journals describing the power which could be generated in this vicinity by the development of all the large waterfalls. In the Fort Benton folio, published in 1899, which includes a portion of the Little Belt Mountains, the Highwood Mountains, and adjoining plains, attention is called to the favorable prospects for artesian water in a portion of the quadrangle. Since the Government irrigation project has been undertaken in Sun and Teton River valleys, a number of scientific and popular articles have been published dealing principally with the surface waters of the region. Following is a chronological list of the more important papers published on the surface-water resources of the Great Falls region, one of which sets forth the prospects for artesian water in the eastern part of the district.

BIBLIOGRAPHY OF THE MORE IMPORTANT PAPERS RELATING TO THE WATER RESOURCES OF THE GREAT FALLS REGION, MONTANA.[a]

LEWIS AND CLARK EXPEDITION, 1804–6. (Coues, 4 vols., 1893.) An account of the journey up the Missouri from St. Louis to the Rocky Mountains, thence to the Pacific coast.

Contains description of the region bordering on the Missouri in the vicinity of Great Falls, Mont. The falls of the Missouri were measured and described.

NEWBERRY, J. S. Surface geology of the country bordering the Northern Pacific Railroad. In Am. Jour. Sci., vol. 30, pp. 337–347. 1885.

Includes a brief description of the surface geology in the vicinity of Great Falls, Mont., with special reference to glacial drift.

NEWELL, F. H. Thirteenth Annual Report U. S. Geological Survey, pt. 3. 1892.

The proposed irrigation system of the Sun River valley and the adjacent region is fully described, pp. 371–386, and the rainfall, topography, and amount of reclaimable land are discussed.

NETTLETON, E. S. Artesian and underflow investigation: Senate Ex. Doc. 41, pt. 2, 52d Cong., 1st sess., pp–78. 1892.

Discusses the surface and underground water of Great Falls district in connection with an explanation of the source of artesian water in eastern South Dakota.

PARKER, M. S. Water power of the falls of the Missouri, Great Falls, Mont. In Engineering News, vol. 32, p. 44. 1894.

The several falls of the Missouri are described, and estimates are made of available power. Reference is made to the Giant Springs.

PARKER, M. S. The Great Falls water power. In Engineering Record, vol. 31, No. 16, pp. 274–275. 1895.

Gives brief description of the various falls of the Missouri at Great Falls, Mont., and detailed illustrations of the power plant at Black Eagle Falls.

WEED, W. H. Fort Benton folio, Montana. Geologic Atlas, U. S., folio No. 55, U. S. Geol. Survey. 1899.

Discusses the general geology and mineral resources of the region, also the probability of obtaining artesian water in the area east of Otter Creek.

WILLIS, BAILEY. Stratigraphy and structure, Lewis and Livingstone ranges, Montana. In Geol. Soc. America, vol. 13, pp. 305–352. 1902.

Describes the physiography of the Lewis and Livingstone mountain ranges and adjoining plains, also character and structural relations of the Algonkian, Carboniferous, Cretaceous, and Quaternary rocks.

NEWELL, F. H. Second Annual Report of the Reclamation Service. 1904.

An abstract of a reconnaissance in Sun River valley, Montana, is included.

NEWELL, F. H. Third Annual Report of the Reclamation Service. 1905.

The proposed irrigation project of the Sun and Teton rivers district is discussed. The water supply of the streams, the storage reservoirs available, and the territory subject to irrigation are described.

UPHAM, WARREN. Outer glacial drift. In Am. Geologist, vol. 34, pp. 151–160. 1904.

The glacial drift of the Northwestern States, including Montana, is discussed. Reference is made to its effect upon the drainage of the Missouri River system.

LEIBERG, J. C. Forest conditions in the Little Belt Mountains Forest Reserve, Montana, and the Little Belt Mountains quadrangle. Prof. Paper No. 30, U. S. Geol. Survey. 1904.

[a] Compiled by W. R. Calvert.

The surface waters of the region and their relation to agricultural, grazing, and forest lands, are included in the discussion.

CALHOUN, F. H. The Montana lobe of the Keewatin ice sheet. Prof. Paper No. 50, U. S. Geol. Survey, 1906.

The glacial history of the Great Falls region is given, with a discussion of the effect of glaciation on the drainage system of the Missouri in that area. Reference is made to artesian conditions near Chouteau.

GEOGRAPHY.

GENERAL FEATURES.

The area treated in this report presents a variety of surface features. It lies in a region which is transitional between plain and mountainous topography and includes portions characteristic of both. Its salient features are broad, gently sloping plateaus bordering the adjacent mountain ranges. These plateaus are traversed by numerous mountain streams, which flow through deep and relatively narrow valleys throughout the eastern portion of the district, but toward the west, where the valleys have been developed in softer rocks, they are usually wide and open. Along the southern margin of the area, from Smith River to the eastern end, the surface of the plains rises gradually by sloping plateaus, culminating in a zone of high, hilly country bordering the Little Belt Mountains, which lie farther to the south. East of Belt Creek and north of the area described the Highwood Mountains rise abruptly above the plains as a cluster of high isolated peaks, reaching an altitude of over 7,000 feet. Between the Highwood and Little Belt mountains is the Otter Creek divide, having at its lowest point an altitude of 4,300 feet. To the east of this divide the country is drained by Arrow Creek and its tributaries and to the west by Belt Creek and its most important branch, Otter Creek, from which the above-described divide derives its name.

PLAINS PROVINCE.

Thoughout the region which lies to the west of Missouri River the country presents topographic features characteristic of the Great Plains, of which it forms the western margin. It is a region of long, gently sloping plateaus traversed by streams having relatively wide valleys. On the summit of this table-land at many places remnants of higher plateaus occur in the form of isolated buttes or long irregular ridges, of which Teton Ridge forms a notable example. Westward the surface rises by successive plateaus toward the base of the Lewis Mountains; the surface features become more diversified; and there are a number of high isolated buttes south of Sun River which form some of the most conspicuous topographic features of the region. There is a moderate range of altitude in the district. The highest points examined occur along the base of the Little Belt

Mountains, where the more prominent summits rise to an altitude of over 5,000 feet. The lowest point in the district is along Missouri River below Big Falls, where the altitude is 2,900 feet above sea level. The average altitude of the region is between 3,500 and 4,000 feet. The greatest variation in altitude for any locality is about 1,300 feet in a horizontal distance of 1½ miles. This occurs between Belt Creek and the summit of Belt Butte at the town of Belt. In the Plains province the relative altitudes of the summits of the plateaus bordering the valley bottoms range from 300 to 600 feet.

DRAINAGE.

The Great Falls region is drained by Missouri River, which crosses its central portion flowing in a northeasterly direction. Its flow varies greatly at different seasons of the year. High water occurs in the late spring and early summer months, when the greatest amount of snow is melted in the mountains, and the low-water mark is usually reached in the month of September. The principal tributary of Missouri River from the north is Sun River, which rises in the Lewis Mountains and, flowing eastward, joins the Missouri at Great Falls. From the south the most important tributaries are Smith River and Belt Creek, the former entering the Missouri about 7 miles above Great Falls and the latter 10 miles below, outside of the area to which this report relates. Smith River drains an extensive country lying between Big Belt and Little Belt mountains, and Belt Creek drains the northern slope of the Little Belt Range (Pl. II, *A*). Teton River crosses the northern part of the area, flowing in an easterly direction. Its principal tributaries are Deep and Muddy creeks, both of which carry considerable water. Throughout the Plains province many of the smaller streams are intermittent, but those draining the northern slope of the Little Belt Mountains always have more or less water, especially in their upper courses.

DETAILED DESCRIPTIONS OF DISTRICTS.

East of the low divide between the Highwood and Little Belt mountains the country slopes gradually northeastward toward Missouri River. It is traversed by several streams draining the slopes of the adjoining mountains. These streams flow through relatively wide valleys that are bordered by gravel-capped terraces of different elevations. Stanford Buttes, a prominent ridge lying between Running Wolf and Surprise creeks, is flat topped, being a remnant of an ancient terrace. To the north and east of this ridge gravel-capped plateaus of lower levels occupy interstream spaces. Toward the Little Belt Mountains the gravel-capped terraces give way to prominent hog-back ridges formed by the sandstone members of the Ellis and

Kootenai formations, which extend in an irregular line of outcrop along the base of the mountains. Skull Butte, a low dome-shaped uplift situated about 6 miles south of Stanford, rises about 200 feet above the surrounding region. South of Skull Butte there are a number of prominent ridges with long gradual slopes to the north and bold escarpments to the south, which overlook valleys excavated in the soft Quadrant shale. In the southwest corner of T. 16 N., R. 10 E., is located Wolf Butte, a very prominent topographic feature in this part of the area.

Broadly viewed, the district lying between the Otter Creek divide and Missouri River is a high plateau sloping northward and deeply dissected by numerous canyons. Belt and Box Elder creeks, Sand Coulee, and Smith River are the principal streams traversing this region. They all flow through deep, narrow valleys. The altitude of the plateau varies from 3,500 feet along Missouri River to 4,500 feet or more along the southern border of the field. The difference in altitude between valley bottom and plateau summit in the northern part of the area is 300 to 400 feet, but toward the mountains this difference increases to over 600 feet. The streams of this district all flow in a northerly direction, except three of the larger tributaries of Smith River—Boston, Ming, and Goodwin coulees—which flow nearly west. Sand Coulee, which is formed by the confluence of a number of canyon tributaries southeast of Stockett, flows northward for about 10 miles, then turns sharply to the west, and for the remainder of its course meanders through a wide, flat-bottomed valley formed by preglacial erosion of Missouri River.

West of the Missouri and south of Sun River the surface rises westward in successive plateaus. The lowest of these plateaus, which lies north of Ulm station and comprises what is locally known as Ulm Bench, has an altitude of about 3,650 feet. West of Ulm Bench is a low saddle separating it from a higher plateau, which in its western extension is surmounted by two isolated buttes forming two of the most conspicuous topographic features of the Plains province. Square Butte, the smaller of the two, is a flat-topped, rectangular-shaped butte, rising abruptly to a height of 500 feet above the surrounding plain (Pl. II, *B*). Fort Shaw Butte, which is in reality a ridge trending northwest, is of equal prominence, but has less precipitous sides. It is less than 1 mile wide, is 2½ miles long, and is located about 2 miles west of Square Butte and almost directly south of Fort Shaw. It has an altitude of about 4,500 feet, rising several hundred feet above the surrounding country. About 3 miles southwest of Shaw Butte is a third, known as Crown Butte, which is also very prominent but somewhat smaller than the two above described. Between Shaw and Crown buttes there is a wide, open valley drained by Little Muddy Creek, a large intermittent stream joining the Mis-

A. DRY BED OF BELT CREEK, NEAR BELT, MONT.

B. NORTHWEST SIDE OF SQUARE BUTTE, SHOWING EAGLE SANDSTONE OVERLAIN BY IGNEOUS ROCK.

souri near Riverdale. South of Little Muddy Creek the surface rises rapidly toward the mountains. Between Sun River and Sims Creek a high gravel-capped plateau of irregular outline occurs, which extends 6 to 7 miles westward. It has an altitude of 3,600 feet and is bordered on the south by the wide, open valleys of Sims Creek and its tributaries. To the west the region consists of prominent ridges and detached buttes, presenting bold escarpments to the north overlooking Sun River valley and long gradual slopes to the south.

Between Sun and Teton River valleys there is a high, gravel-capped, sloping plateau, which continues from the western margin of the district in a more or less modified form to Muddy Creek of Sun River. The southern edge of this plateau is very irregular from the west boundary of the district to a point about 3 miles north of Lowry, but from this point eastward it becomes sharply defined by a line of bluffs about 200 feet high. In its western extension this plateau increases in altitude and culminates in a high crescent-shaped ridge with a bold north-facing escarpment overlooking Deep Creek valley. Eastward the ridge terminates in a number of isolated hills, the larger of which are locally known as Priest Buttes. From Priest Buttes southward to Freezeout Lake the east face of the plateau is deeply serrated by numerous canyons. Bordering this plateau on the east is a belt of level country, imperfectly drained, which is locally known as Freezeout Basin. Near the middle of this basin and at the base of Freezeout Butte is Freezeout Lake, 1½ miles wide and about 3 miles long, which contains water only a small portion of the year. East of Freezeout Basin the surface rises slightly to a level table-land or plateau, which is locally known as the Freezeout Bench. The elevation of this plateau varies from 3,900 to 4,000 feet.

The area between Teton River and its principal tributary from the north, Muddy Creek, is in its central portion a level plateau or bench having an altitude of 3,900 feet. It is locally known as Burton Bench. On the east, where this plateau is crossed by the terminal moraine of the Keewatin ice sheet, its surface is hilly, such as is characteristic of a morainal district, but to the west the surface rises gradually toward the base of the high bluffs occurring on either side of Ralston Gap. West of this prominent line of bluffs the country, which is crossed in its northern part by Muddy Creek, is rolling. North of Muddy Creek there is a low line of bluffs 100 to 200 feet high, the margin of which is included within the area described. Between Teton River and its most important tributary, Deep Creek, is an area containing in its central portion typical badlands topography, with long, irregular ridges culminating in sharp peaks, the most prominent of which are Teton Buttes. On the north

side of this high ridge the surface slopes away to Teton River, while to the south there is a wide, gravel-capped terrace which borders Deep Creek on the north.

GEOLOGY.[a]

STRATIGRAPHY.

GENERAL OUTLINE.

The formations occurring at the surface throughout the area to which this report relates consist mainly of sedimentary rocks with igneous intrusions in the form of dikes or laccoliths. The latter occur especially in the regions bordering the adjacent mountain ranges. The strata in general lie nearly horizontal or dip at a relatively small angle to the northeast away from the mountains. They are representative of Carboniferous, Jurassic, Cretaceous, Tertiary, and Quaternary systems. The distribution of these formations, except the Tertiary and certain members of the Quaternary, is shown on the geologic map (Pl. I), and their structural relations, particularly those affecting the occurrence of underground water, are illustrated in the cross sections. The table on pages 15–16 sets forth the order, age, characteristic features, thickness, and water capacity of the formations.

[a] A detailed report of the geology of the Great Falls region will appear in Bulletin No. 356 of the Geological Survey.

Geologic formations in the Great Falls region, Montana.

System.	Formation.	Character of deposit.	Average thickness.	Water capacity.	Quality of water.	Areal distribution.
			Feet.			
Quaternary and Tertiary.	Alluvium	Light-colored silt, sand, and clay with local gravel beds.	20 to 40	Water bearing	Generally good; varies with character of formation from which alluvium is derived.	Occupies valleys throughout the district.
	Lacustrine deposits	Fine-grained, light-colored silt and clay.	Not determined.	Water bearing	Good	Occur as a valley filling in all the larger valleys in front of the terminal moraine.
	Morainal deposits	Unassorted mixture of sand and gravel in which bowlders of varying size are irregularly scattered, consisting mainly of gneiss, quartzite, granite, and limestone.	Not determined.	Contain some water	Variable	Occupy the area lying south of Missouri River between Great Falls and Belt Creek; also the area north of that stream across the east side of Fort Benton Bench, along the north side of Teton Ridge, and across the east end of Burton Bench.
	Bench gravels	Sand, gravel, sandy clay, and conglomerate.	25 to 40	Generally contain water, although not a large amount; often source of small marginal springs.	Water generally hard, owing to abundance of calcareous cementing material in gravel.	On extensive areas lying east of Otter Creek divide; also highlands between Sun and Teton rivers.
Cretaceous.	Montana. Claggett	Dull-green and gray sandy shale, clay, and impure sandstone; also massive light-gray and very dark-green, iron-stained conglomeratic sandstone.	[a] 670	Probably contains more or less water.	Good	On area south of Sun River and west of Crown Butte, also north of Sun River over a part of the district lying west of a line connecting Lowry with Bas Christian's ranch. Areal distribution not shown on map.
	Montana. Eagle	Massive gray sandstone containing large iron-stained concretions 3 to 10 feet in diameter, which are fossiliferous. Sandstone layers alternating with sandy shale in lower part.	90	Water bearing. Source of springs around Square and Shaw buttes.	Good	Exposed underneath the igneous rock capping Square, Shaw, and Crown buttes. Occupies summit of bluffs at Lowry; caps Freezeout and Priest buttes and gives rise to a conspicuous line of bluffs extending northward west of Chouteau past Ralston Gap to the northern margin of the area. Distribution not shown on map.
	Colorado	Upper part composed of dark-colored shale with a few thin sandstone layers. Lower part consists of massive gray sandstone, often concretionary, iron-stained, containing thin layers of pebbly conglomerate.	1,600 to 1,800	Shale of upper part of formation generally not water bearing. Basal sandstone members contain large amount of water.	Water from shale highly mineralized. Sandstone contains good water.	Exposed along south side of Highwood Mountains from Belt Creek to the east border of the district. Basal sandstones cap the plateau region between Red Buttes and Missouri River. Occupies an extensive area lying between Missouri River and line of bluffs formed by Eagle sandstone above described. Not differentiated from Montana on geologic map.

[a] Upper limit of formation not determined.

Geologic formations in the Great Falls region, Montana—Continued.

System.	Formation.	Character of deposit.	Average thickness.	Water capacity.	Quality of water.	Areal distribution.
			Feet.			
Cretaceous.	Kootenai	Massive gray sandstone, red sandy shale and clay with an occasional bed of white limestone. The sandstone predominates throughout the lower portion, while red shale, clay, and limestone constitute the upper members. About 60 feet above the base there is a bed of workable coal.	400 to 500	Sandstone members containing large amount of water.	Very good	Occupies surface area over a great part of the district lying between Smith River and Belt Creek and is the surface formation of high plateaus south of Otter Creek. East of Otter Creek extends as a narrowing outcrop along northern side of Little Belt Mountains.
Jurassic.	Morrison	Variegated shale and clay containing sandstone layers one above middle of formation, cinnamon brown in color and bone-bearing. Limestone layers sometimes present in lower part.	75 to 120	Sandstone members may contain small amount of water.	Probably would be more or less mineralized.	Outcrops as a narrow band below Kootenai rocks in sides of canyons bordering streams draining northern slope of Little Belt and Big Belt mountains from Smith River to Otter Creek. East of Otter Creek its outcrop zone, which is of varying width, generally occupies the inner face of low hogback ridges of Kootenai rocks bordering the Little Belt Mountains.
	Ellis	Dove-colored limestone comprising basal member overlain by reddish-brown, coarse-grained sandstone coarsely conglomeratic at base.	80 to 120	Sandstone member probably contains water.	Water probably hard, for sandstone is bound together by calcareous cement.	Between Smith River and Otter Creek outcrop area limited to canyons traversing the plateau region bordering the Little Belt Mountains.
Carboniferous.	Quadrant	Sandstone, red and green shale and clay, and limestone with an occasional bed of gypsum in lower part.	400 to 500	Contains some water	Water generally impure; several sulphur springs issue from this formation.	In the upper part of Belt Creek valley and extending eastward throughout a zone of varying width along the base of the Little Belt Mountains to east end of district.
	Madison	Massive light-gray limestone, white limestone, and more or less argillaceous shale.	100 exposed.	Upper part not water bearing.		In Smith River valley in T. 17 N., R. 3 E., in Sand Coulee and its tributary canyons, in the vicinity of Stockett, and along the northern base of Little Belt Mountains from Belt Creek to east end of district.

CARBONIFEROUS SYSTEM.

MADISON LIMESTONE.

The Madison limestone is very conspicuous, bordering the north side of the Little Belt Mountains, but in the greater part it lies outside of the area here described. The only exposures in the district are found along East Fork of Sand Coulee and its tributaries, where a local doming of the beds exposes about 100 feet of the formation. The distribution of the limestone is shown on the geologic map (Pl. I). Along the flanks of the Little Belt Mountains, outside of the area to which this report relates, the limestone has a thickness of about 1,000 feet, and three members have been recognized by previous workers. The lower member, which is more or less argillaceous, has been called the Paine shale, the more massive limestone of the middle part of the formation the Woodhurst limestone, and the top member the Castle limestone. The Castle limestone forms the "sluicebox canyon," the lower end of which is at Riceville. It is a part of the upper division of Madison limestone, which is exposed at numerous places in the vicinity of Stockett.

That portion of the formation exposed in the area here described consists mainly of limestone, interbedded with calcareous clay. The limestone is usually massive and compact, and is of medium to dark gray color, weathering light. It occurs in beds 10 to 12 feet thick, and is generally relatively pure. At Stockett, 15 feet of oolitic limestone was observed, and at another locality on Ming Coulee, where about 140 feet of the limestone was exposed, the lowest member contains bands of dark-colored chert. Fossils were collected from the limestone at Stockett, also on the head of Ming Coulee, outside the area described.

These fossils have been examined by Dr. G. H. Girty, who regards them as of Mississippian age. In the Little Belt Mountains the Madison limestone is said to carry a typical Mississippian fauna.

The Madison limestone is believed not to be water-bearing, especially that portion which outcrops within this area. Several wells have penetrated the limestone in the vicinity of Stockett and Sand Coulee, and have invariably failed to obtain water.

QUADRANT FORMATION.

The Quadrant formation consists of sandstone, shale, and limestone, with beds of gypsum in the lower part. It lies outside of the area studied except in a few localities, notably on Belt Creek, near Riceville, on Little Otter Creek, 2½ miles above its mouth, along the base of the Little Belt Mountains from Otter Creek to near the southeast corner of the area described, and in the central part of Skull Butte.

In the exposure near Riceville, the basal member of the Quadrant consists of reddish sandy shale with an occasional layer of gypsum. Overlying this member, to which Weed[a] has applied the term Kibbey sandstone, the deposits consist largely of shale with interbedded limestone and some sandstone, designated the Otter shale by the same author. The total thickness of the formation as exposed near Riceville is less than 500 feet.

The formation is not important as a water bearer, for throughout the greater part of the district it lies too deep to be reached by ordinary well borings, and as the upper member is shale and limestone and the lower gypsum-bearing soft sandstone, it is highly probable that if water were obtained it would be considerably mineralized. In the vicinity of Wolf Butte a number of sulphur springs issue from the shale members of this formation, and wherever springs are found in it the water contains a large amount of objectionable salts.

JURASSIC SYSTEM.

ELLIS FORMATION.

The Ellis formation is composed of a basal limestone of variable thickness ranging from 20 to 60 feet, above which lies a coarse conglomerate that passes upward into a medium-grained sandstone, light brown in color and more or less thin bedded. The limestone and conglomerate contain Jurassic fossils. Those in the conglomerate are sometimes fragmentary, but more often combined with pebbles of limestone and quartzite several inches in diameter. The component parts of the conglomerate are bound together by a calcareous cement. The total thickness of the formation is about 125 feet, and it rests unconformably upon the Quadrant and Madison formations. Though no practical tests have been made of the water capacity of the formation, it is probable that the sandstone of the upper part would readily absorb water under favorable conditions.

MORRISON FORMATION.

The Morrison formation, which is extensively exposed along the Rocky Mountain Front Range in southern Montana and Wyoming, is also believed to occur along the northern base of the Little Belt Mountains. In previous investigations in this field the Morrison formation has not been recognized, and the beds comprising it have been included in the "Cascade" formation. During the field season of 1906 dinosaur bones, believed by C. H. Gilmore to be of Jurassic age, were found at one horizon in many different localities, and at one exposure,

[a] Weed, W. H., Geologic Atlas U. S., folio 55, U. S. Geol. Survey, 1899, p. 2.

about 30 feet below the bone-bearing horizon, a green shale was seen containing a distinctly fresh-water fauna later than the Ellis formation. These sediments, which are here provisionally regarded as constituting the Morrison formation, consist of sandstone and bright-colored sandy shale, with an occasional layer of impure limestone, generally in lenticular form. It lies with apparent conformity on the Ellis, and is overlain conformably by the Kootenai. The thickness varies from 60 to 120 feet, but the exact limits of the formation are often difficult to determine. Fragments of bones have been found at different horizons throughout the overlying Kootenai formation, but thus far none have been discovered in this region sufficiently well preserved for specific determination. It is possible that future investigation may prove that the sediments here tentatively regarded as belonging to the Morrison formation are in reality a basal member of the Kootenai.

The formation is generally exposed in a narrow band on the inner rim of a low ridge formed by the harder overlying rocks of the Kootenai formation. It outcrops all along the base of the Little Belt Mountains from the east end of the district to Smith River. Good exposures occur along the upper courses of Sage, Skull, Running Wolf, Hazlett, Surprise, Geyser, and Otter creeks, and in the bluffs for some distance back from the mountains along Belt Creek, Sand Coulee, Smith River and its principal tributary, Ming Coulee. The following section will show the succession of the beds:

Section of the Morrison formation on the east side of Belt Creek, Montana, in NE. ¼ sec. 30, T. 18 N., R. 7 E.

	Feet.
Gray, thin-bedded sandstone	17
Pebbly conglomerate occurring in lenses	5
Maroon and green shale	52
Green shale capped by 1½ feet of gray sandstone	5
Calcareous sandstone, weathering light brown	5
Green shale	20
Massive sandstone, weathering light brown	7
Dark-green shale containing thin limestone layers	9
Ellis formation.	
	120

The so-called Morrison formation is believed not to be an important water-bearing formation in this general district. It is composed largely of shale and clay, which are apparently not sufficiently porous to absorb or transmit underground water freely. It is possible, however, that some of its sandy members may contain water; but it is inferred from their lithologic character and the absence of springs throughout their exposed areas that they are not water bearing.

CRETACEOUS SYSTEM.

KOOTENAI FORMATION.

The Kootenai formation includes the upper third of the "Cascade," the Dakota, and the basal red shale included in the Colorado formation as described by W. H. Weed[a] in the Fort Benton folio. The name Cascade, as referring to a Cretaceous formation, was first used by that author in his description of the rocks of the Fort Benton quadrangle to apply to a series of beds ranging in thickness from 225 to 500 feet. The lower part of the formation, as originally described, consisted of lavender-tinted sandstone and highly colored shale and clay with massive gray sandstone above containing at its base a workable bed of coal.

During the present investigation, as previously stated, saurian bones, believed by some geologists to be of Jurassic age, were discovered in the lower half of the so-called "Cascade" formation, which indicates that these beds are probably of Morrison age, although vertebrate remains continue to occur to the top of the Kootenai. Between a horizon 45 feet below the coal bed and the top of the "Cascade" formation, as above defined, fossil plants of Kootenai age were collected at four different horizons, which establishes the lower Cretaceous age of this portion of the formation. On the east side of Spanish Coulee, a tributary of Smith River, at a horizon about 150 feet above the "Cascade" formation, in beds the stratigraphic equivalent of which near Belt are regarded provisionally by Weed as of Dakota age, a large collection of Kootenai plants were secured from dark coaly shale associated with red and green shale and clay. Overlying this plant-bearing bed there is about 200 feet of sediment consisting of red shale and sandstone, not differing materially in stratigraphy from beds immediately underlying the plant horizon. For this reason, together with the apparent absence of the Dakota flora in these beds, this member is provisionally regarded as of lower Cretaceous age and included in the Kootenai formation. It is overlain by dark-colored shale and sandstone of the Colorado formation, in the lower part of which were discovered marine saurian remains.

In this report it is not regarded as advisable to employ the name Cascade for the following reasons: The term has not been as extensively used in the literature as the older term Kootenai; its usage would necessitate redefining the term in order to separate its lower member, which is now believed to be Morrison; and the beds immediately overlying the formation can not be differentiated paleontologically from the "Cascade," both being of lower Cretaceous age.

[a] Weed, W. H., Geologic Atlas U. S., folio 55, U. S. Geol. Survey, 1899.

rendering it necessary to base the upper limit of the formation in question purely on lithologic grounds.

The Kootenai formation is about 450 feet thick and consists of alternating layers of sandstone and shale with the former predominating, especially in the lower half. The sandstone varies in thickness from 10 to 80 feet and is more or less massive in character. In the upper part shale predominates and is interbedded with thin layers of impure sandstone. At Belt, on the east side of Belt Creek, where a complete section was measured, the basal member of the formation consists of a sandy shale interbedded with sandstone, the latter predominating, and the whole having a thickness of about 60 feet. This member sometimes consists of firm, massive sandstone, with only a small percentage of shale. It is overlain by coal, which here has a thickness of 6 feet, including a few thin partings. Above the coal there is a dark, coaly shale 5 to 6 feet thick, covered by 38 feet of massive light-gray sandstone. This sandstone is followed in ascending order by 138 feet of beds consisting mainly of alternating layers of sandstone, red shale, and clay, with an occasional limestone lens in the lower part. Above this alternating series of sandstone, red shale, and limestone there is about 200 feet of red shale, which constitutes the topmost member of the formation. On the north side of Skull Butte the base of the Kootenai consists of a soft, light-gray, massive sandstone, but in other respects the portion of the formation exposed in this locality agrees closely with the beds exhibited at Belt Butte. A section of the Kootenai on the north side of Skull Butte is given below:

Section of the Kootenai formation on the north side of Skull Butte, Mont.

	Feet.
Reddish sandy shale.	
Gray thin-bedded sandstone	1½
Reddish sandy shale with layers of sandstone in the lower part	21
Greenish-gray sandstone, weathering dark, thin-bedded above, clay-ball conglomerate below	4
Reddish sandy shale, with layers of sandstone in lower part	27
Gray cross-bedded sandstone, clay-ball conglomerate in lower part	5½
Reddish sandy shale	30
Soft, thin-bedded sandstone	20
Gray, massive sandstone, clay-ball conglomerate	3½
Red sandy shale	38
Gray, massive sandstone, clay-ball conglomerate	5
Red sandy shale	24
Calcareous sandstone, alternating with sandy shale	20
Light and dark gray, fine-grained, massive sandstone	86
Coal and coaly shale (estimated)	6
Soft, massive, gray sandstone	62
	353½

Next to the Colorado the Kootenai has the greatest areal distribution of all the formations outcropping within the area. It occupies the surface over a great part of the district lying between Smith River and Belt Creek and is the surface formation of the high plateaus south of Otter Creek. Beyond Otter Creek it is exposed as a band of varying width, which narrows eastward.

The Kootenai is the principal water-bearing formation of the Great Falls region. As above stated, it consists mainly of sandstone and sandy shale. The sandstone is medium to coarse-grained and porous so that it readily absorbs water when the structural conditions are favorable. Along each side of Otter Creek and its tributaries from the south, also in Sand Coulee and its tributaries, the various sandstone members of the Kootenai formation are the source of numerous springs, and in the eastern part of the territory, where this sandstone is overlain by impervious Colorado shale, it contains artesian water.

COLORADO FORMATION.

The Colorado formation is well developed in this general region, being represented by about 1,600 feet of beds. In its type locality in the vicinity of Fort Benton, only a few miles to the north, it is essentially a shale formation, but throughout this region the lower part contains a number of prominent sandstone members. West of Great Falls, where the formation is typically developed, its basal member consists of a soft, massive sandstone somewhat concretionary, which is about 30 feet thick. Above this sandstone there is approximately 35 feet of sediment composed largely of dark-colored shale, with a few sandstone beds. This dark-colored shale is overlain by gray, coarse-grained, massive sandstone, containing concretionary layers and an occasional thin bed of soft, sandy shale, the whole having a thickness of about 80 feet. Above the sandstone for about 300 feet the beds consist mainly of alternating layers of sandstone and shale. These are followed by 700 feet of beds composed largely of uniformly dark-colored shale, which constitutes the uppermost member of the Colorado.

The Colorado formation is exposed throughout a wide area extending along the south side of the Highwood Mountains from Belt Creek southeastward to the east border of the district. Its basal sandstone members occupy the summit of Red Buttes and continue westward as a plateau capping to the Missouri River valley. Smith River and its tributaries cut the basal sandstone of the Colorado, exposing the underlying Kootenai rocks. The Colorado formation occupies the surface of the highland lying between Missouri and Sun rivers, also north and west of these streams to beyond the Teton. Its areal distribution is larger than any other formation within the district.

The shale of the Colorado formation, which constitutes nearly two-thirds of its entire thickness, is not water bearing, but the sandstone comprising its basal portion, which is medium to coarse grained and porous, carries an abundance of water. Throughout Ulm Bench, which is capped by basal Colorado sandstone, a number of wells have been sunk that furnish a large supply of excellent water derived from this formation. It is also the source of well-water supply on the highlands between Smith and Missouri rivers. East of Smith River there are a number of small springs situated along the margin of the detached plateaus which issue from the base of the Colorado sandstone. A typical spring of this character is shown in Pl. V, *A*.

MONTANA GROUP.

The Montana is extensively developed in the western part of the Great Falls region. It is represented within the area examined by the Eagle and Claggett formations. West of the district fossils were obtained from it which are believed to be of Judith River age. No Pierre shale was recognized in this general vicinity, although the formation is probably represented in the steeply dipping beds that skirt the base of the Lewis Mountains. While no careful examination was made of the Cretaceous formations bordering the base of the Lewis Mountains, it is believed that the various members that constitute the Montana group in the Judith River basin are here represented.

EAGLE SANDSTONE.

The Eagle sandstone consists of massive gray sandstone containing large iron-stained concretions 3 to 10 feet in diameter, which are fossiliferous. Sandstone layers alternate with sandy shale in the lower part. It has a thickness of about 90 feet and is exposed in places underneath the igneous rock capping Square, Fort Shaw, and Crown buttes (see Pl. II, *B*). It occupies the summits of the bluffs at Lowry where fossils characteristic of the formation were collected. Farther north it caps Freezeout and Priest buttes and gives rise to a conspicuous line of bluffs extending northward west of Chouteau and past Ralston Gap to the northern margin of the district. The distribution of the formation is not shown on the geologic map. The Eagle sandstone is a water-bearing formation, as is shown by the numerous small springs which issue from its base around Fort Shaw and Square buttes.

CLAGGETT FORMATION.

Overlying the Eagle sandstone is the Claggett formation, which consists of dull green and gray sandy shale, clay, and impure sandstone; also massive, light-gray and very dark-green, iron-stained,

conglomeratic sandstone. In the upper part of that portion of the formation exposed in the area examined there is an erosional unconformity, which may be local, exhibiting a marked change in the character of the beds immediately above and below the contact. This apparent unconformity is well exposed on the north face of a high bluff on the south side of Sun River about 7 miles below Augusta, where the following section was taken:

Section of a portion of the Claggett formation on the south side of Sun River, Mont.[a]

	Feet.
Sandstone, dark green, conglomeratic, interbedded with sandy, leaf-bearing shale	50
Unconformity?	
Sandstone, massive, gray, and sandy shale, fossiliferous throughout	125
Sandstone, soft greenish gray	95
Shale, sandy and dark green, interbedded with sandstone layers which are concretionary	100

The Claggett formation occupies the surface south of Sun River and west of Crown Butte, also north of Sun River throughout a part of the district lying west of a line connecting Lowry with Bas Christian's ranch. The areal distribution of the formation is not shown on the geologic map. The sandstone members of the Claggett formation probably contain more or less water, although as far as could be ascertained no wells have been sunk in them.

QUATERNARY SYSTEM.

TERRACE DEPOSITS.

Throughout a great part of the territory lying east of Otter Creek divide and north of Sun River most of the interstream spaces are capped by bench gravel. This deposit consists of gravel and sand ranging in thickness from 10 to 40 feet and having smooth surfaces sloping gently away from the uplift. The component parts of the gravel, especially in the terraces north of Sun River which have their source to the west in the Lewis Mountains, are mainly sandstone, limestone, and chert, with a small per cent of igneous rock, the whole being sometimes bound together by calcareous cement. In the eastern part of the area the gravel of the terraces is more diversified, containing a larger percentage of igneous rock derived from the Little Belt Mountains to the south.

[a] Fossils collected from the locality where the above section was measured are regarded by T. W. Stanton as of the same age as forms collected from the Claggett formation in Judith River basin.

Gravel deposits of four different periods have been recognized. The earlier gravel, which is often cemented into conglomerate, occurs only in limited areas, capping some of the more prominent buttes and ridges, while the later is widely distributed, especially throughout the eastern part of the field. This bench gravel probably ranges in age from Tertiary to later Quaternary age, having been brought down by streams from the Little Belt Mountains and spread by them over the lower plain country as their courses were shifted from time to time. The distribution of the terrace deposits is not shown on the geologic map.

The gravel terraces of the Great Falls district usually contain some water. The amount, however, is not large, and a well sunk in them rarely obtains a sufficient quantity for both stock and domestic purposes of an average-sized ranch. That these gravels contain water, however, is shown by the fact that wherever they occupy extensive areas they are the source of numerous small marginal springs. The water contained in them is derived from rainfall.

GLACIAL DEPOSITS.

Glacial deposits of late Wisconsin age occupy a considerable area throughout the Great Falls region. The terminal moraine of the Keewatin ice sheet enters the district at the east end of Burton Bench, extending south to Teton River, where it turns to the east and follows along the northern side of Teton Ridge to the vicinity of Dutton. From here it extends diagonally southeastward past Benton Lake, across Missouri River to Sand Coulee near Gerber station, where it makes a sharp bend eastward and continues thus past the head of Red Coulee, thence northeastward to Belt Creek, where it passes off the northeast margin of the area. Its location and extent, as worked out by Calhoun,[a] are shown on the geologic map. The Keewatin ice sheet, extending into the region from the northeast, dammed up Missouri River and its tributaries, forcing the former to abandon its channel in many places, some of which were not reoccupied on the retreat of the ice. The abandoned channel, a portion of which is shown on the accompanying map, extends from the mouth of Sand Coulee, 4 miles south of Great Falls, northeastward in meandering course to the mouth of Belt Creek, where it unites with the present Missouri. In addition to the morainal deposits described above, there was deposited during the occupation of this general region by the ice extensive lake sediments in front of the terminal moraine. Much of this material has been removed by post glacial erosion on the higher lands,

[a] Calhoun, F. H. H., Montana lobe of the Keewatin ice sheet: Prof. Paper U. S. Geol. Survey No. 50, 1906.

but all the larger valleys in front of the moraine are filled with these sediments. Lake deposits of two different periods have been recognized by glaciologists in this region—an earlier and a later deposit. The limits of the earlier lake sediments can be ascertained only by bowlders lodged on the summits of the plateaus, while much of the deposits of the more recent lake still remains as a filling in the larger valleys. The distribution of the lake sediments is not shown separately, but is included with the valley wash.

The glacial deposits—especially the more recent lake sediments filling the valleys—are water bearing, and in some places in front of the terminal moraine they are the source of artesian water. The artesian water of Burton Bench is derived from granitic gravels overlain by impervious glacial clays deposited in front of the terminal moraine, and in Box Elder Creek valley is a flowing well, which is believed to have a similar source.

ALLUVIUM.

The alluvial deposits of this general region exhibit the usual diversified character, especially along the larger streams, such as Missouri, Sun, and Teton rivers, the deposits varying in width from one-fourth to 1 mile. The material is composed of fine silt, sand, clay, and gravel, which have been transported by streams in times of high water and deposited at different places along their courses. Along Missouri River from the base of the Big Belt Mountains northeastward to the vicinity of Great Falls the river flows in a meandering course through a wide plateau plain of alluvium, but east of that point it flows through a narrow canyon in which only small detached areas of alluvium are found.

The alluvial deposits generally contain a large amount of water and are the source of well water along nearly all the valleys in this region. The water in this formation is generally relatively pure, although the alluvium of some of the smaller valleys, especially in the Colorado shale areas, contains highly mineralized water.

STRUCTURE.

As the movement of water underground is governed to a certain extent by the structure of the formations, a brief description of the structural relations of the rocks of different parts of the district is here given, attention being called to the manner in which these structures affect the prospects for artesian water. Throughout the Plains portion of the region described the structure is relatively simple and the rocks lie nearly horizontal, dipping with a small angle to the north and east away from the mountains; but in the mountainous portion the structure is more complex.

LITTLE BELT MOUNTAINS.

The general structure of the Little Belt Mountains, which border this area on the south, is that of an anticlinal uplift with sharply dipping sides and a flat summit. In the central portion of the range the stratified rocks lie nearly horizontal, while along the northern flanks of the uplift, as shown on the head of Avoca Creek, the limestone dips at an angle of 15° to 20° toward the lower Plains country. The simple structure of the northern part of the uplift has been considerably modified by the intrusion of igneous rocks in the form of laccoliths, which have caused local doming of the strata in many places. Only one of these laccolithic domes occurs within the area described, but there are others, such as are found east of Kibbey and in the head of Dry Wolf Creek, whose marginal structure extends into this area. In the vicinity of the larger intruded masses of igneous rock the dips are often steep and variable, but in that portion of the mountain front where local intrusions have not disturbed the strata they dip away normally from the uplift at angles of 6° to 12°, lessening gradually toward the lower Plains country, thus producing ideal structural conditions for the occurrence of artesian water on the plains.

HIGHWOOD MOUNTAINS.

The Highwood Mountains, which border on the north the eastern end of the area described, are structurally different from the Little Belt Range. They consist of a group of isolated peaks which have been formed by igneous intrusion in Cretaceous rocks which were horizontally bedded or slightly inclined eastward. Subsequent to this intrusion stream erosion has removed much of the softer rock, leaving the harder rock standing as a cluster of peaks above the surrounding plain.

LEWIS AND BIG BELT RANGES

The Lewis and Big Belt ranges, being more remote from the field investigated, were not examined, but their broader structural features, as worked out by previous investigators, are given below.

The Lewis Mountains, lying to the west of the district and constituting the Rocky Mountain Front Range of northern Montana, have been formed by an overthrust fault of considerable magnitude, extending along the east side of the range, which superimposes Algonkian strata on upper Cretaceous rocks. The extent of the thrust in the vicinity of Chief Mountain, which lies to the north, is said to be 7 miles in a horizontal direction. Under these conditions it is apparent that rocks occupying the surface throughout the adjoining plains on the east will in their westward extension pass under the higher portions of the mountains instead of extending normally up

their flanks, thus producing structural relations not favorable to the occurrence of artesian water in the western part of the Great Falls region. From observations made in the vicinity of Cascade, the northern end of the Big Belt Mountains is formed by extensive masses of igneous rock penetrating upper Cretaceous sediments, which are in some places horizontally bedded and in others sharply folded. It is possible that the overthrust fault which extends along the face of the Lewis Range turns eastward along the northern side of the Big Belt Mountains, but this point was not ascertained in the field.

WATER RESOURCES.

SOURCE.

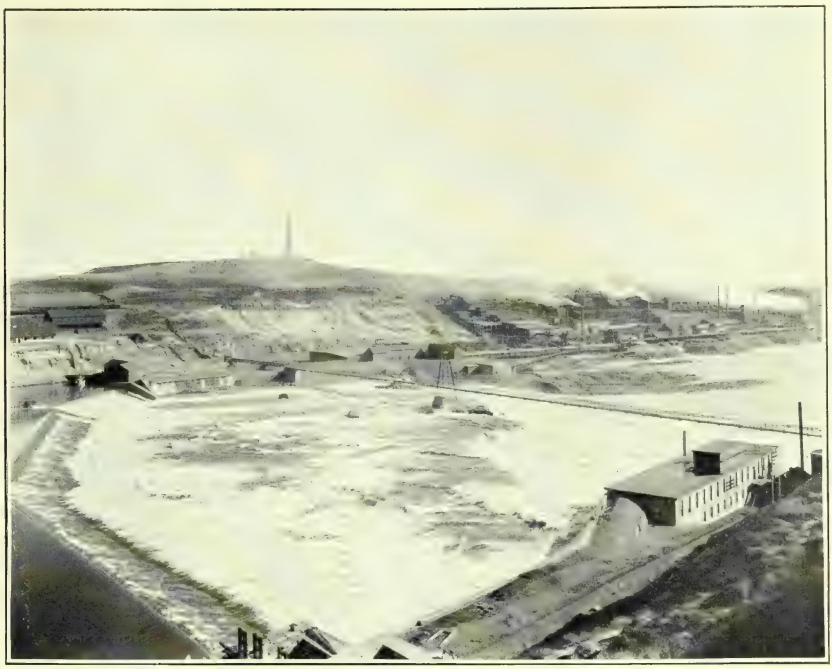
The source of water supply of the Great Falls region is found mainly in the adjoining mountain ranges. These mountains rise to altitudes of 8,000 to 10,000 feet, where there is a relatively large precipitation and a heavy snowfall. They are covered to a greater or less extent by coniferous forests, and thus serve as natural reservoirs regulating the run-off of the district. The numerous streams traversing the Great Falls region head high in the slopes of the adjoining mountains. Here they gather a large amount of water from melting snow, which is carried out of the mountains into the plains or is absorbed by the upturned edges of the porous rocks over which the streams pass, thus becoming available as artesian water lower down on the plains when the overlying impervious strata are penetrated by well borings. Extensive fires have denuded much of the mountainous land which was formerly densely forested, leaving bare rocks and dead timber and causing the run-off to be more rapid.

SURFACE WATERS.

STREAMS.

MISSOURI RIVER.

The principal stream of the district is Missouri River. It enters the area near Cascade and flows in a northerly direction to the vicinity of Great Falls, where it changes to a more easterly course, continuing thus to the border of the field. That portion of the stream lying above Great Falls flows in a meandering course through a wide valley, but below this point it enters a narrow valley with precipitous bluffs, passing over a number of cataracts collectively known as the Great Falls of the Missouri River (Pl. III, *A* and *B*, and Pl. IV, *A* and *B*). The drainage area of Missouri River at Cascade, Mont., is estimated at 18,295 square miles. Its largest tributaries from the south are Smith River and Belt Creek, and from the west and north Sun and Teton rivers, the latter entering the Missouri in the vicinity of Fort Benton outside of the area to which this report relates.



A. DAM AT BLACK EAGLE FALLS AND THE ANACONDA CONSOLIDATED COPPER AND MINING COMPANY'S SMELTERS, GREAT FALLS, MONT.

B. RAINBOW FALLS OF MISSOURI RIVER, 4 MILES BELOW THE TOWN OF GREAT FALLS, MONT.

There are a number of medium to large size intermittent streams with relatively large drainage areas entering the river from either side. Those from the south are Bird Creek, Castner Coulee, Sand Coulee, Box Elder Creek, and Red Coulee, and from the west Little Muddy Creek. The flow of Missouri River is by no means constant, but varies greatly with the season. According to discharge measurements made at Cascade, Mont., during four consecutive years from 1902 to 1905, inclusive, it had a maximum flow of over 22,000 second-feet and a minimum of about 1,800 second-feet, the mean varying from about 2,000 to 18,000 second-feet. As previously stated, the greatest volume of water is carried by the stream during the months of June and July, and the low-water mark is generally reached in the month of September. The results of observations made on the flow of Missouri River at Cascade are given in the following table:

Estimated rate of discharge of Missouri River at Cascade, Mont., 1902–1905, by months.

[Measurements made by W. W. Schlecht and L. V. Branch.]

Date.	Discharge in second-feet.			Date.	Discharge in second-feet.		
	Maximum.	Minimum.	Mean.		Maximum.	Minimum.	Mean.
1902.				1904.			
July 17–31	6,900	3,170	4,847	April	12,830	5,150	8,409
August	2,950	1,810	2,171	May	21,710	12,090	14,925
September	2,305	1,915	2,057	June	20,600	11,350	16,660
October	2,950	2,380	2,720	July	11,350	3,600	7,436
November	4,030	2,550	3,176	August	3,480	2,305	2,898
				September	2,380	1,915	2,167
1903.				October	3,600	2,465	2,979
April	9,300	4,730	6,536	November	3,600	3,260	3,416
May	12,700	7,700	9,958	December	4,490	2,740	3,597
June	22,700	12,100	17,953				
July	12,700	2,845	7,302	1905.			
August	3,420	2,090	2,372	March	3,930	3,340	3,721
September	2,550	1,970	2,274	April	4,320	3,120	3,635
October	3,170	2,645	3,056	May	4,320	3,450	3,944
November	6,300	3,170	4,470	June	10,410	4,060	8,081
December	9,900	2,740	6,083	July	10,070	2,600	4,518
				August	2,900	1,800	2,147
1904.				September	2,020	1,720	1,929
January			[a] 6,000	October	2,600	1,720	2,159
February			[a] 6,000	November 1–27	3,930	2,600	3,158
March			[a] 6,000				

[a] Estimated.

Discharge measurements of Missouri River at Cascade, Mont., in 1902 and 1906.

[Drainage area, 18,295 square miles.]

Date.	Hydrographer.	Second-feet.
1902.		
July 21		5,537
September 9		1,891
November 6		3,131
1906.		
April 24	G. Edson	6,190
May 12	do	7,880
June 3	do	14,400
June 25	Edson and Richards	10,400
August 20	R. Richards	2,300
September 17	Grover and Richards	2,620
October 31	R. Richards	3,480

According to measurements of the flow of Missouri River, made by E. T. Nettleton[a] in September, 1891, this stream loses 834 second-feet of water between the town of Great Falls and Fort Benton, a distance of about 45 miles. These measurements are supposed to have taken into account the amount added to Missouri River by Belt and Highwood creeks and by Giant Springs. That from the former two is inconsiderable, but the latter adds materially to the total flow.

SUN RIVER.

Sun River, the largest tributary of Missouri River in this district, rises high in the Lewis Mountains. The main stream is formed by the junction of North and South forks of Sun River, which takes place about 3 miles northeast of Augusta in the northwest corner of T. 8 N., R. 5 W. From this point the stream pursues an easterly course through an open valley to Great Falls, where it joins Missouri River. The area drained by Sun River comprises the greater portion of that part of the high eastern slope of the Rocky Mountain Front Range extending from parallel 47° 30′ to 48° and a portion of the adjoining Plains province 25 to 30 miles wide extending from the base of the mountains eastward to the vicinity of Great Falls. The high mountainous portion of its drainage area is covered with snow throughout the greater part of the year, while on the adjoining plains more arid conditions prevail. The principal tributary of Sun River from the north is Muddy Creek, which drains the high plateau between Sun and Teton rivers, emptying into the Sun near Vaughn. It is an intermittent stream of minor importance. From the south Sims Creek joins Sun River near the town of Sims, and a few miles farther west Spring and Dry creeks come in from the same side. Sun River has a large flow of water, the maximum being reached during the early summer months when the largest amount of snow is melted on the mountains. By far the greater part of the water of this stream comes from North Fork of Sun River, which is several times larger than South Fork, having its drainage area higher on the slopes of the Lewis Mountains. Discharge measurements of Sun River at the town of Sun River, about 20 miles above its mouth, are given below:

Discharge measurements of Sun River at Sun River, Mont., 1906.

Date.	Hydrographer.	Second-feet.
April 10	Morse and Edson	344
April 15	H. M. Morse	359
May 3	G. Edson	684
May 21	do	1,240
May 22	do	1,160
May 30	do	2,140
June 19	Edson and Richards	1,510
July 16	R. Richards	506
August 17	do	74
October 6	do	204
November 6	Follansbee and Richards	396
November 16	do	[b] 1,440

[a] See Bibliography, p. 9.

[b] Ice running; value doubtful.

A. CROOKED FALLS OF MISSOURI RIVER, NEAR GREAT FALLS, MONT.

B. BIG FALLS OF MISSOURI RIVER, 9 MILES NORTHEAST OF GREAT FALLS, MONT.

SMITH RIVER.

Smith River has its source far to the southeast in the vicinity of the Castle Mountains, and flowing northwest drains the highland area between the Big Belt and Little Belt mountains. It enters the area described near the center of the south line of T. 17 N., R. 3 E., and flowing in a northeasterly direction joins Missouri River at a point near Ulm. Within the area described the stream flows in a meandering course through a deep but narrow valley. The gradient of the lower course of the stream is about 7 feet to the mile. The largest tributary of Smith River is Hound Creek, entering from the west, near Orr. It drains the northern end of the Big Belt Mountains, some of its tributaries extending high up the slopes of that range. From the east three intermittent streams enter Smith River—Boston, Ming, and Goodwin coulees. Smith River has a flow of nearly 400 second-feet during the months of May and June, but in the late fall its flow is very much smaller, as is shown by the following discharge measurements:

Discharge measurements of Smith River at Truly, Mont., 1905–6.

Date.	Hydrographer.	Second-feet.
1905.		
March 7	Porter and Bird	163
May 11	Stockman and Porter	125
September 1	A. P. Porter	31
1906.		
April 9	Morse and Edson	423
May 11	G. Edson	397
July 12	R. Richards	317
November 28	do	[a] 79.9

[a] Wading section.

TETON RIVER.

The northern portion of the area treated in this report is drained by Teton River. This stream has its source on the eastern slope of the Lewis Mountains, but it does not extend far back into the uplift. After leaving the mountains it pursues a southeasterly course to the vicinity of Chouteau, where it makes a pronounced bend and flows northeastward past Collins and joins Missouri River in the vicinity of Fort Benton. Its largest affluents are Muddy and Deep creeks, the former entering from the northwest below Collins, and the latter from the south near Chouteau. These streams both rise in the foothills of the mountains and have a continuous flow throughout the year. The flow of Teton River is not large, especially in the vicinity of Chouteau, but near the mountains the amount is greater. At a point about 7 miles above Chouteau the stream bed is often dry throughout the late summer months, but, while the surface flow of this portion

of the stream is small, there is apparently a very strong underflow. Spring Creek, a tributary of this stream, is formed by a number of springs having their source in the valley wash. It rises in Teton Valley in the northwest part of T. 24 N., R. 5 W., and flows roughly parallel to Teton River at a distance of one-half to three-fourths of a mile from it for about 10 or 12 miles to where it enters the main stream. Discharge measurements of Teton River have been made near Belleview and in the vicinity of Chouteau. These are given in the following tables:

Discharge measurements of Teton River near Belleview, Mont., 1904–1906.

Date.	Hydrographer.	Second-feet.
1904.		
November 27	A. P. Porter	58
1905.		
May 8	Stockman and Porter	48
October 12	Gordon Edson	56
November 4	do	51
1906.		
April 12	G. Edson	25.2
May 9	do	43.1
June 22	Edson and Richards	17

Discharge measurements of Teton River near Chouteau, Mont., 1904–5.

Date.	Hydrographer.	Second-feet.
1904.		
November 9	A. P. Porter	7.3
1905.		
May 9	Stockman and Porter	8
October 13	Gordon Edson	3
1906.		
April 13	Morse Edson	7.2
May 9	G. Edson	4.6
June 23	Edson and Richards	7.8

BELT CREEK.

This stream rises in the northern part of the Little Belt Mountains, flows north across the east-central part of the district, draining the territory lying west of the Highwood Mountains, and entering the Missouri about 12 miles northeast of Great Falls. It is a vigorous mountain stream, which carries a large flow of water in its upper course throughout all seasons of the year, especially near the mountains, but at the town of Belt all this water sinks to an underflow (see Pl. II, A) during the late summer months, leaving the stream bed dry. The loss is probably due to the fact that soft porous sandstone forms the floor of Belt Creek valley. A view of the dry

bed of Belt Creek is shown in Pl. II, *A*. From a short distance below the town of Belt to its mouth the stream has a small but continuous flow. Discharge measurements above the town of Belt are as follows:

Discharge measurements of Belt Creek near Belt, Mont., in 1905–6.

Date.	Hydrographer.	Second-feet.
1905.		
March 17	Porter and Bird	8.0
May 12	L. R. Stockman	7.8
June 11	A. P. Porter	578
1906.		
April 20	G. Edson	4.62
May 18	do	160
May 19	do	155
June 1	do	357
July 14	R. Richards	190
November 10	Follansbee and Richards	3.55

OTTER CREEK.

Otter Creek is one of the largest tributaries entering Belt Creek from the east. It rises on the northeastern slope of the Little Belt Mountains near Barker and flows north for about 6 miles, thence northwest, joining Belt Creek near Armington. It receives several small spring-fed tributaries from the south, including Little Otter Creek, Bundy Coulee, Swan Coulee, and Ford Creek. Its branches from the north, which have their source in the Highwood Mountains, are Williams and Cora creeks—the former entering near Spion Kop and the latter 2 miles above its mouth. No discharge measurements have been made of Otter Creek, but it has considerable water throughout all seasons of the year, which is supplied mainly by a number of large springs along its course.

OTHER SMALL STREAMS.

The area lying between Belt Creek and Smith River is drained by Box Elder Creek and Sand Coulee. Box Elder Creek rises on the high plateaus about 3 miles west of Riceville, flows northward in a direction roughly parallel to Belt Creek, and enters the Missouri about 9 miles northeast of Great Falls. This stream carries only a small flow of water. Sand Coulee, an intermittent stream with a large drainage area, is formed by the union of several small canyon tributaries southeast of Stockett. It continues northward to a point about 6 miles below Stockett, where it makes a sharp turn to the west and meanders through a wide level-floored valley for about 7 miles, entering Missouri River about 4 miles above Great Falls. That portion of its valley through which the stream flows from the point where it makes the sharp turn to the west is a part of the preglacial valley of

the Missouri, which extends from the mouth of Sand Coulee eastward to Box Elder Creek and then northeastward to near the mouth of Belt Creek, where it reunites with the present channel.

East of Otter Creek there is a prominent ridge constituting a low divide between the Highwood and Little Belt mountains which has been named the Otter Creek divide. East of this divide the drainage is all to the northeast into Arrow Creek, which is a small tributary of the Missouri, entering a short distance above the mouth of Judith River. Arrow Creek, which has its source on the southern slope of the Highwood Mountains, flows eastward, passing out of this district in T. 18 N., R. 11 E. Its principal affluent is Surprise Creek, which rises at the base of Wolf Butte and pursues a northeasterly course, uniting with the main stream outside of the area here described. Running Wolf Creek rises higher up the slopes of the Little Belt Mountains farther to the southeast and flows northeasterly past Stanford Buttes, joining Judith River outside of the district. East of Running Wolf Creek there are several small creeks crossing the extreme southeast corner of the district which belong to the Judith River system. These are Skull, Willow, and Sage creeks.

LAKES AND SWAMPS.

The lakes occurring within the Great Falls district are of two kinds—those on the table-land, which hold flood water during a small portion of the year, and the artificial lakes, which are used as storage reservoirs for the most important irrigation systems. The largest of the natural lakes is Benton Lake, located on the highlands about 9 miles nearly due north of Great Falls. It is about 1 mile wide and 2½ miles long, and is said to have formerly held water all the year. At present the flood water which it receives during the spring sinks away, leaving the lake bed dry throughout the entire summer. It is situated in front of the terminal moraine of the Keewatin ice sheet and is probably of glacial origin. Freezeout Lake, situated in the center of an area of glacial lake deposits in Freezeout Basin, holds a small amount of water a portion of the year. There is also another small, dry lake on the plains about 3 miles southeast of Dutton. Northeast of Priest Buttes are two artificial lakes, known as Priest Lakes, which are formed by seepage water from the Cascade Land Company's canal, and south of Ralston Gap there is a small lake used as a storage reservoir. Lakes or reservoirs are of frequent occurrence throughout the district. One of considerable size is found on the table-land north of Lowry, and another, now abandoned, south of Square Butte, in the Little Muddy Creek valley. Many other smaller lakes of this character are found throughout the district, the locations of which are given on the geologic map. On Burton Bench, near

Teuchot home ranch, there are a number of small lagoons or lakes fed by springs which contain water throughout the year.

To the west of the area treated in this report and along the base of the Lewis Mountains there is a zone in which local mountain glaciers have deposited morainal material over wide districts bordering the larger streams. Throughout these glaciated areas there are innumerable small lakes and swamps which furnish water to the mountain streams crossing them.

UNDERGROUND WATERS.

GENERAL STATEMENTS.

The water-bearing rocks of the Great Falls region are confined mainly to the basal Colorado and the Kootenai formations, where a number of sandstone beds occur which are porous and imbibe water freely when conditions are favorable. There are other formations within the district that have sandstones that probably contain more or less water. These are the Eagle and Claggett sandstones of the Montana formation and the coarse-grained conglomeratic sandstone of the Ellis formation. Around the sides of Square and Fort Shaw buttes a number of small springs issue from the base of the Eagle sandstone. In the Kootenai formation several water-bearing horizons are found. The massive gray sandstone overlying the coal, which ranges in thickness from 25 to 80 feet, is the source of a number of springs along Otter Creek, and wherever the coal is mined, especially where the sandstone forms the roof, considerable difficulty is encountered with water from this formation. Above the sandstone overlying the coal there are a number of massive sandstones interbedded with red shale, which, when they occupy summits of plateaus, have numerous small springs issuing from their base. These Kootenai sandstone beds are the sources of numerous small springs wherever they are exposed from the eastern margin of the field to Smith River. West of Stockett, however, they are overlain by basal sandstones of the Colorado, which cap the plateau summits west and south of Sand Coulee, extending to beyond Missouri River and including the bench land north of Ulm. Throughout this area springs are of frequent occurrence at the base of the Colorado sandstone, and wherever well borings on the summits of the plateau have entered this sandstone a good supply of water has usually been obtained.

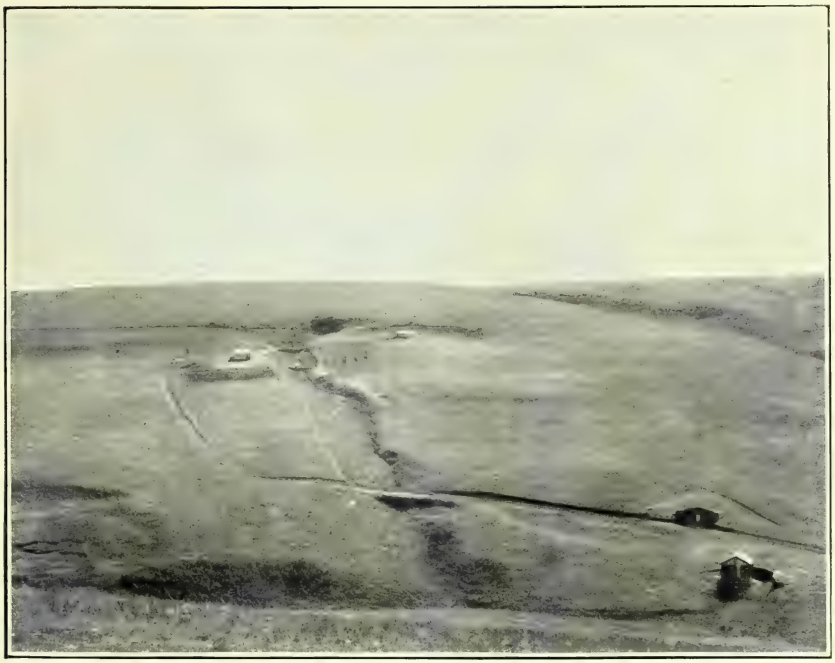
SPRINGS.

DISTRIBUTION.

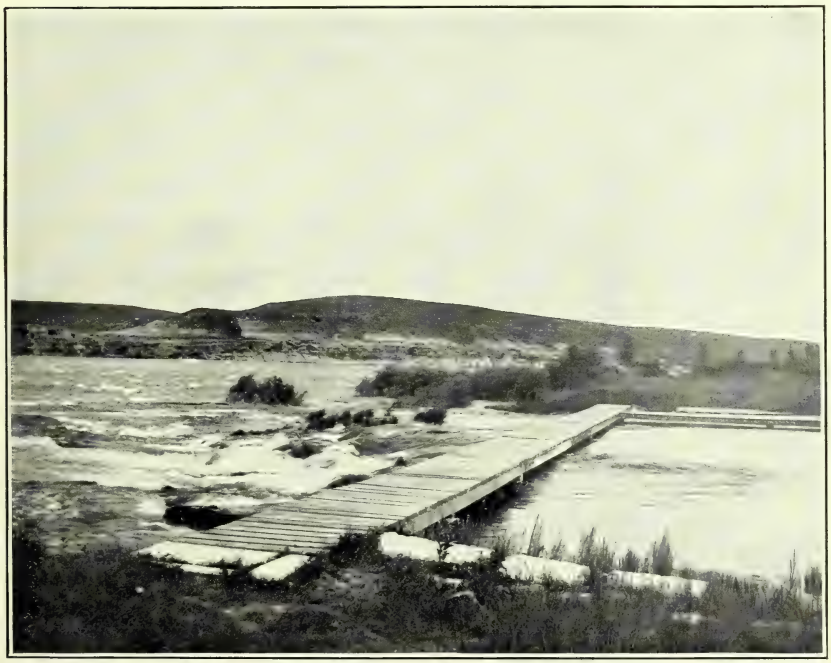
One of the most valuable sources of domestic and stock water supply in the Great Falls district is found in the numerous springs which occur along the upper courses of the smaller mountain streams

and in the valleys of the larger streams throughout the lower Plains country. Along the northern slope of the Little Belt Mountains springs are very abundant. The zone bordering the mountains is essentially a plateau region traversed by numerous mountain streams which flow through deeply cut valleys. In the bottom of these valleys and along their sides at different elevations above the streams springs of moderate flow occur at frequent intervals. Their source is the various water-bearing sandstones of the Kootenai formation, which extend southward far up the slopes to the high hilly zone bordering the mountains where there is an increased precipitation, and the sandstones absorb a large amount of water. Lower down on the plains the mountain streams cut and expose these sandstones, leaving the water free to escape as springs in the sides of the plateaus and in the lower portions of the valleys. Springs of this character are most abundant along Otter and Belt creeks, Sand Coulee, Smith River, and their principal tributaries (see Pl. V, *A*). They are usually not large, but afford a steady supply of good water when properly developed. West of Missouri River springs are less numerous. Several are found issuing from the base of the Eagle sandstone on the sides of Square and Fort Shaw buttes. At one locality on the west side of Square Butte water from a number of these small springs which have been developed is piped 2 miles to the Toman stock ranch, where it is utilized for domestic purposes (see Pl. II, *B*). On the north side of Sun River the high gravel-capped plateau is more or less dissected by canyons leading southward. In these canyons and in the heads of coulees tributary to them springs are frequent. They have their source in the gravel terrace which caps the plateau, or in the underlying Eagle sandstone. The flow, though not large, is continuous, the water being used mainly for stock purposes by the Flowerree Cattle Company. A few small springs are found along Muddy Creek of Sun River northwest of Vaughn and along the base of the bluffs at the upper end of Burton Bench.

In Sun and Teton River valleys there are a few large springs which derive their water from the underflow of these streams. Probably the largest spring of this character is found in Teton Valley about 7 miles above Chouteau, where a sufficient amount of water issues from the valley wash to supply a stream of considerable size, known as Spring Creek. In Sun River valley at Lowry is a spring of similar size, which is utilized for both irrigation and stock purposes. This spring has a large flow of excellent water, which enters Sun River a short distance below Lowry. Another spring, somewhat smaller, is found on the opposite side of the river at Skinner and Heikie's ranch, and farther down the river, a short distance above the intrusive dike which crosses Sun River valley about 1 mile west of Fort Shaw, there is a small area where numerous springs issue



A. SPRING AT BASE OF COLORADO SANDSTONE, 12 MILES SOUTH OF GREAT FALLS, MONT.



B. GIANT SPRINGS, NEAR GREAT FALLS, MONT.

from the v. 'ey wash. Springs are not infrequent in Sun River valley between Lowry and Augusta. At Sam Larkin's ranch, 6 miles below Aug. sta, a spring issues from the base of a low gravel-capped ter .ce, and has a strong flow of water throughout the year. Other springs of ·· ·· ·lar character examined in this part of Sun River valley are ; n the table on pages 42–50, with their source, quality, and approxim e yield.

A few sp ng are found along Missouri River between Cascade and Great Falls which are used for domestic and stock purposes, although in the majority of cases in this vicinity the water supply is derived from shallow wells. Along the base of the Big Belt Mountains on the east side of the river springs are more numerous, and in many ·· have been given the chief consideration in locating

GIANT SPRINGS.

Near Great Falls are some very large springs which present unique geologic features and an interesting question as to the source of the water (see Pl. V, *B*). These springs, locally known as Giant Springs, are located on the south bank of Missouri River about 3 miles below Great Falls. They have a very large flow of relatively pure water, which appea s at the surface through large joints in a medium to coarse-grained sandstone belonging to the Kootenai or lower Cretaceous rocks. On either side of the main spring for a short distance are smaller springs flowing from the joints, and directly opposite it in the bed of the river there is a large spring, which is apparent during low water. The Giant Springs were discovered by Captain Lewis, of th Lewis and Clark Expedition, in 1804, and in his description w re spoken of as the "largest fountain in the United States."

According to measurements made by E. T. Nettleton[a] the flow of these springs is approximately 638 cubic feet per second, an amount which, converted into gallons, is the equivalent of over 400,000,000 gallons every twenty-four hours—a veritable underground river. The fact that the water of Giant Springs issues from rocks at the water's edge and in the bed of the river renders it difficult to measure their exact flow. In order to ascertain this amount, measurements were taken of the total flow of Missouri River above and below the springs; the difference between these two measurements is assumed to be the quantity furnished to the river by the springs. It is readily seen from the above figures that these springs rank among the largest in the United States. The water, which boils up with considerable force, is clear, blue, and relatively pure, containing no more dissolved salts than the average well water of the region. It has a temperature of about 50° F.

[a] See Bibliography, p. 9.

No spring deposits occur in the immediate vicinity of Giant Springs, and the water is not generally regarded as possessing therapeutic value. It is not utilized at present, but is allowed to flow into the river. There are, however, a few improvements, such as sidewalks, etc., which make it possible for tourists to view the springs from the most advantageous points.

A chemical analysis of the water was made several years ago by James A. Dodge, of the University of Wisconsin, and a field analysis of the water was made during the past field season by W. R. Calvert. These analyses are given below.

Analyses of water of Giant Springs near Great Falls, Mont.

MINERAL ANALYSIS.

[Grains per gallon.]

$CaSO_4$	14.04
$CaCO_3$	4.38
$MgCO_3$	4.98
$NaCl$	.56

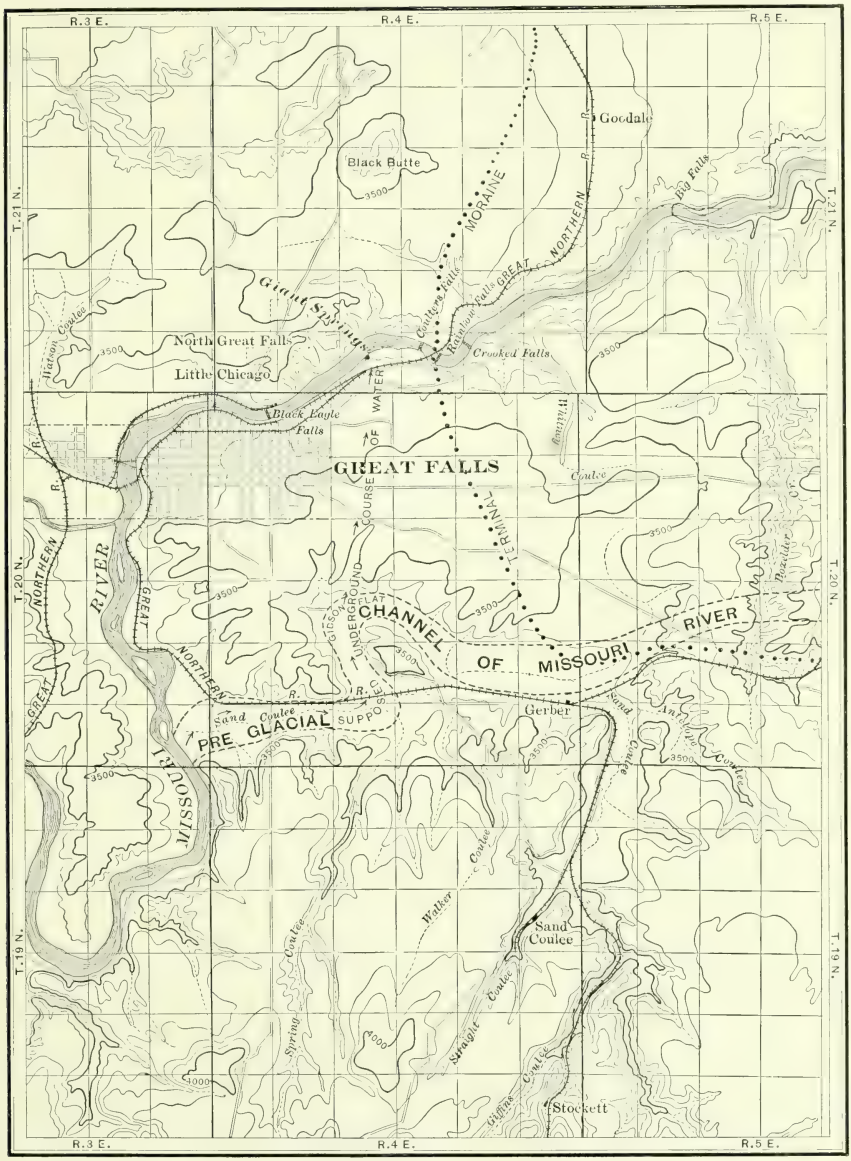
Traces of borates and potassium and lithium.

FIELD ANALYSIS.

[Parts per million.]

Turbidity	0
Color	0
Iron	0
Calcium	Moderate.
Total hardness	97
Total alkalinity	340
Alkaline carbonates	0
Alkaline-earth carbonates	339
Sulphates	300
Chlorides	10

From a careful study of the geologic relations in the vicinity of Great Falls, it is believed by the writer that the water of Giant Springs is derived from the subriver flow of the Missouri which leaves the valley of that stream near the mouth of Sand Coulee as an underflow and passes down its preglacial channel, which extends up Sand Coulee, into Gibson Flat, an oxbow in the old river channel. From here by a subterranean passage through porous Cretaceous sandstone and sandy shale, which dip in a favorable direction for its transmission, it makes its escape to the present Missouri River, where it appears in the form of Giant Springs (see Pls. V, *B*, and VI). It is further believed by the writer that the jointing, which is here well developed with the major joint planes extending in a north-south direction, is an important factor in the underground movement of the water. It is also possible that a fault in this vicinity further facilitates the underground passage of the water, but no positive



MAP OF GREAT FALLS DISTRICT, MONTANA, SHOWING PREGLACIAL CHANNEL OF MISSOURI RIVER AND COURSE OF UNDERGROUND WATER.

evidence of this was seen. Well borings in lower Sand Coulee and Gibson Flat demonstrate that the materials filling the old valley are largely coarse river sediments, well adapted for rapid percolation of water.

From the above it is readily seen that along the supposed underground course of the water from the mouth of Sand Coulee to where it appears at the surface as springs, the physical conditions are such as to permit the passage of a large volume of water, an amount believed to be equivalent to that furnished by the Giant Springs.

WELLS.

While springs are the principal source of domestic water supply in the Great Falls region, there are a number of localities, especially in the larger valleys, where the greater part of such water is derived from shallow wells rarely exceeding 20 feet in depth. On the summits of some of the plateaus bordering the Little Belt Mountains, where dry farming is successfully practiced, wells obtain water at depths varying from 100 to 300 feet, depending on the locality. To the west and north of Great Falls, throughout the highland districts, wells are usually shallow, rarely being sunk below the base of the gravel terraces, which vary from 25 to 40 feet in thickness and cover extensive areas. In the larger valleys traversing the western part of the district wells are usually shallower than those on the highland, and water is more abundant. Throughout Burton Bench, north of Teton River, they vary from 20 to 100 feet, the deeper ones being artesian. A few deep wells have been dug in the vicinity of Great Falls, three by the Great Falls Meat Company on the table-land east of Great Falls, two by the Copeland Brothers near the south end of Sun River bridge, and others farther up Missouri River, one on Odell ranch and another at Ulm. The deepest boring in this portion of Montana occurs about 6 miles east of Dutton, where an oil prospect hole, known as the Banatyne well, has been sunk to a depth of 1,500 feet. Records of the Copeland Brothers, Banatyne, and Odell wells are given below, and on subsequent pages occur well tables giving the location, depth, quantity, and quality of water of a number of representative wells in the Great Falls district.

Records of Copeland Brothers' wells near the south end of Sun River bridge, Great Falls, Mont.

WELL NO. 1.

	Feet.
Fine sand	0– 4
Gumbo	4–15
Blue clay	15–31
Sand and gravel, water bearing	31–33
Red sandstone	33–43

Records of Copeland Brothers' wells near the south end of Sun River bridge, Great Falls, Mont—Continued.

WELL NO. 1—Continued.

	Feet.
Ferruginous sandstone	43–47
Blue shale	47–59
Gray shale	59–85
Gray sandy rock	85–100
Light-red rock	100–105
Dark-red rock	105–112
Gray compact sandstone	112–122
Blue shale	122–134
Red rock	134–144
Sandstone with shaly layers	144–147
Light-red rock	147–157
Soapstone	157–227
Impure sandstone	227–229
Gray shale	229–244
Impure sandstone	244–247
Gray shale	247–252
Impure sandstone	252–255
Gray shale	255–263
Impure sandstone	263–265
Gray shale	265–277
Sandstone and shale	277–282

WELL NO. 2.

Fine sand	0–8
Medium fine sand	8–25
Gumbo	25–36
Blue clay	36–52
Red rock	52–62
Ferruginous sandstone	62–66
Blue shale	66–81
Red rock	81–103
Fine gray sandstone	103–107
Light-red rock	107–123
Blue shale	123–131
Gray sandstone	131–143
Brown shale	143–157
Gray shale	157–167
Soapstone	167–207
Light-red rock	207–219
Impure sandstone	219–223
Dark-red rock	223–233
Black shale	233–247
Light-red rock	247–250
Gray shale	250–260
Impure sandstone	260–263
Gray shale	263–265
Impure sandstone	265–266
Blue shale	266–274
Impure sandstone	274–276

Records of Copeland Brothers' wells near the south end of Sun River bridge, Great Falls, Mont—Continued.

WELL NO. 2—Continued.

	Feet.
Dark shale	276–280
Impure sandstone	280–283
Gray shale	283–289
Blue sandstone	289–297
Brown shale	297–300
Blue sandstone	300–310
Impure limestone	310–318
White limestone	318–370
Brown limestone	370–417
White limestone	417–459
Blue limestone	459–519
Impure limestone	519–541
Brown limestone	541–569
Blue limestone	569–581
White limestone	581–643

Record of Banatyne well, 6 miles east of Dutton, Mont.

	Feet.
Yellow clay	0– 74
Shale	74– 280
Sand, containing salt water and gas	280– 285
Sandy shale	285– 358
Black sand	358– 365
Shale	365– 500
Sand, containing salt water	500– 509
Sand and gritty shale	509– 605
Soft, white conglomerate	605– 780
Hard conglomerate	780– 870
Fine blue sand	870– 880
Hard blue shale	880– 900
Hard shale in thin layers	900– 950
Dark-blue shale	950– 975
Black shale	975–1,040
Hard bluish sandstone	1,040–1,130
Black shale	1,130–1,160
Red limestone	1,160–1,200
Red sandstone	1,200–1,240

It is believed that the so-called red limestone encountered at a depth of 1,160 feet below the surface represents the upper part of the Kootenai formation.

Record of Odell well in Missouri River, south of Great Falls, Mont.

	Feet.
Alluvium	0– 20
Sand	20–145
Clay	145–205
Gravel	205–212

Partial list of springs of Great Falls region, Montana.

No.	County.	Locality.	Township, etc.	Owner.	Temperature.	Quantity.	Material from which spring issues.	Approximate elevation.	Is supply continuous?	Use.
					°F.			Feet.		
1	Teton	Choiteau	SW. ¼ sec. 30, T. 25 N., R. 5 W.	On Government land		Small	Blue shale	4,100		Stock.
2	do	do	NE. ¼ sec. 18, T. 25 N., R. 5 W.	Frank Ralston	52	do		4,100	Yes	Domestic and stock.
3	do	do	SW. ¼ sec. 28, T. 24 N., R. 5 W.	On Government land		do	Sandstone	4,050		Stock.
4	do	do	SW. ¼ sec. 1, T. 24 N., R. 4 W.	H. R. Thompson	50	do	Alluvium	3,800	Yes	Domestic and stock.
5	do	do	SE. ¼ sec. 24, T. 23 N., R. 5 W.			do	Blue shale	4,200		
6	do	do	SE. ¼ SE. ¼ sec. 20, T. 23 N., R. 4 W.	P. Grossen	52	Medium	Sandstone	3,900	Yes	Domestic, stock, and irrigation.
7	do	do	SW. ¼ sec. 18, T. 23 N., R. 4 W.	S. T. Cattle Co.	53	Small	do	3,950	Yes	Stock.
8	Cascade	do	NW. ¼ sec. 13, T. 22 N., R. 4 W.	J. Thorn						
9	do	Augusta	SW. ¼ sec. 28, T. 22 N., R. 4 W.	— Flowerree	55					Do.
10	Lewis and Clark	do	NW. ¼ sec. 26, T. 21 N., R. 6 W.	Jim Lytle					Yes	
11	do	do	Sec. 13, T. 21 N., R. 6 W.	— Flowerree				4,300		
12	do	do	NW. ¼ sec. 35, T. 21 N., R. 5 W.	Clark Lytle	48				No	
13	Cascade	do	NE. ¼ sec. 2, T. 21 N., R. 5 W.	— Flowerree						
14	do	do	NE. ¼ sec. 6, T. 21 N., R. 4 W.	do		Small				Do.
15	Lewis and Clark	do	SE. ¼ SW. ¼ sec. 2, T. 20 N., R. 6 W.	P. Mayer	52			4,000	No	Irrigation.
16	do	do	NE. ¼ sec. 1, T. 20 N., R. 6 W.	C. C. Woods	54			4,000	Yes	
17	do	do	NW. ¼ NW. ¼ sec. 6, T. 20 N., R. 5 W.	S. Larkin	52	Small		4,100		
18	do	do	SE. ¼ NE. ¼ sec. 7, T. 20 N., R. 5 W.	J. S. Lytle				4,000	Yes	
19	do	do	SE. ¼ sec. 9, T. 20 N., R. 5 W.	P. Bickle		Small		4,000		
20	Cascade	do	NW. ¼ sec. 5, T. 20 N., R. 4 W.	— Flowerree	54				Yes	
21	do	Hepler	NE. ¼ sec. 13, T. 21 N., R. 4 W.	do	51	Small				Domestic and stock.
22	do	do	SW. ¼ sec. 14, T. 21 N., R. 4 W.	do	52	do				Stock.
23	do	do	NW. ¼ sec. 35, T. 22 N., R. 4 W.	do	49	Medium	Blue shale		Yes	Do.
24	do	do	NE. ¼ sec. 27, T. 22 N., R. 4 W.	do	52				Yes	Do.
25	do	do	NE. ¼ sec. 2, T. 20 N., R. 4 W.	do						
26	do	do	NE. ¼ sec. 4, T. 20 N., R. 3 W.	do		Medium	Alluvium			
27	do	do	NE. ¼ sec. 10, T. 20 N., R. 3 W.	D. B. Todd		do	do		Yes	
28	do	do	NW. ¼ sec. 35, T. 20 N., R. 3 W.	Carl Meickel	48	do	Blue sandstone		Yes	Domestic and stock.
29	do	do	NW. ¼ SE. ¼ sec. 5, T. 20 N., R. 2 W.	On Government land	52	do		3,500	Yes	Stock.
30	do	do	NE. ¼ sec. 20, T. 20 N., R. 2 W.	do		Small			Yes	Do.
31	do	do	NW. ¼ sec. 20, T. 20 N., R. 2 W.	do		do			Yes	Do.
32	do	do	SE. ¼ sec. 4, T. 19 N., R. 3 W.	Carl Meickel			Sandstone			Stock and irrigation.
33	do	Sun River	SW. ¼ sec. 33, T. 22 N., R. 1 E.	Sun River Stock and Land Co.		Small				Stock.
34	do	do	SE. ¼ SE. ¼ sec. 34, T. 21 N., R. 2 W.	On Government land	50	Medium			Yes	Do.
35	do	do	NE. ¼ sec. 35, T. 20 N., R. 2 W.	Toman Bros.		do			Yes	Do.

36	do	Cascade	NW. ¼ SE. ¼ sec. 5, T. 19 N., R. 1 W.	do			do		4,000	Yes	Domestic and stock.
37	do	do	SW. ¼ NE. ¼ sec. 9, T. 19 N., R. 1 W.		57		Small		4,000		
38	do	do	SW. ¼ SE. ¼ sec. 9, T. 19 N., R. 1 W.		54		Medium		3,800	Yes	Do.
39	do	Truly	Sec. 29, T. 19 N., R. 2 E.	J. Ferguson			do	Sandstone	3,400		Domestic.
40	do	do	Sec. 28, T. 19 N., R. 2 E.	G. L. Ferguson			Small				Domestic and stock.
41	do	do	Sec. 30, T. 19 N., R. 3 E.	Erison Dent			Medium	Sandstone			Irrigation.
42	do	do	Sec. 28, T. 19 N., R. 3 E.	M. Coy			do	do			
43	do	do	Sec. 32, T. 19 N., R. 3 E.	—— Wood						No	
44	do	do	SE ¼ sec. 31, T. 19 N., R. 3 E.	Shaw & De Pon			Small				
45	do	do	NW. ¼ sec. 32, T. 19 N., R. 3 E.	do			Medium				
46	do	do	E. ½ sec. 25, T. 18 N., R. 2 E.	—— Johnson				Sandstone	3,400		
47	do	do	SE. ¼ sec. 17, T. 18 N., R. 2 E.	J. A. Perrine					3,600		
48	do	do	Sec. 32, T. 18 N., R. 2 E.	—— Misolf			Small				
49	do	do	Sec. 25, T. 18 N., R. 2 E.	J. J. Patterson				Clay			Domestic.
50	do	do	NW. ¼ sec. 8, T. 18 N., R. 3 E.								
51	do	do	E. ½ sec. 10, T. 18 N., R. 3 E.	—— Bisson			Small				
52	do	do	Sec. 15, T. 18 N., R. 3 E.	—— Hensler			Medium	Sandstone		No	
53	do	do	SW. ¼ sec. 4, T. 18 N., R. 3 E.					do			
54	do	do	Sec. 23, T. 18 N., R. 3 E.	—— Kinsey				do			
55	do	do	Sec. 21, T. 18 N., R. 3 E.	P. Linquist			Small	do			Do.
56	do	do	S. ½ sec. 21, T. 18 N., R. 3 E.				do	do			
57	do	do	SW. ¼ sec. 20, T. 18 N., R. 3 E.	—— Steele			do				
58	do	do	S. ½ sec. 29, T. 18 N., R. 3 E.	A. Engstrom			do				
59	do	do	Sec. 2, T. 17 N., R. 2 E.	H. E. Wood			do	Sandstone		Yes	Do.
60	do	do	do	T. J. S. Wingley			do	do			
61	do	do	NW. ½ NE. ¼ sec. 29, T. 17 N., R. 2 E.	Sutton Bros			Medium	Alluvium		Yes	
62	do	do	NE. ¼ sec. 34, T. 17 N., R. 2 E.	—— Hansen			do	Sandstone		Yes	
63	do	do	do				Small	do		Yes	
64	do	do	SW. ¼ sec. 8, T. 17 N., R. 3 E.	Huntsbarger Bros.				do			Stock.
65	do	do	NE. ¼ sec. 6, T. 17 N., R. 3 E.	M. E. Bruneau				do		Yes	Domestic.
66	do	do	SW. ¼ NW. ¼ sec. 2, T. 17 N., R. 3 E.	T. Splain			Medium		3,500		Irrigation and stock.
67	do	do	NW. ¼ sec. 11, T. 17 N., R. 3 E.	—— Ryane			Small	Sandstone			Domestic.
68	do	do	NE. ¼ sec. 14, T. 17 N., R. 3 E.	J. Cocren			Large		3,500	Yes	Domestic and stock.
69	do	do	Sec. 26, T. 17 N., R. 3 E.	B. Marxer			do	Sandstone	3,600	Yes	
70	do	do	Sec. 21, T. 17 N., R. 3 E.	W. R. Goodell			Medium	do		Yes	
71	do	Great Falls	SW. ¼ sec. 33, T. 22 N., R. 2 E.	Sun River Stock and Land Co.			Small	Shale		Yes	
72	do	do	NE. ¼ sec. 11, T. 20 N., R. 2 E.	—— Sindblade			Large	Alluvium	3,350	Yes	
73	do	do	NE. ¼ sec. 7, T. 20 N., R. 3 E.	K. B. McIver			do	do		Yes	Domestic and stock.
74	do	do	SW. ¼ sec. 9, T. 19 N., R. 4 E.	C. Jaeckel			Small				Stock.
75	do	do	Sec. 12, T. 19 N., R. 4 E.	H. J. Clark			Medium	Sandstone	3,500	Yes	Do.
76	do	do	NW. ¼ sec. 12 T. 19 N., R. 4 E.	J. A. Walker			do	do	3,500	Yes	Domestic and stock.
77	do	do	NE. ¼ sec. 4, T. 19 N., R. 4 E.	F. E. Goon			Small	do	3,400	Yes	Do.
78	do	do	SE. ¼ sec. 4, T. 19 N., R. 4 E.	I. O. Proctor			do	do	3,400	Yes	Do.
79	do	do	Sec. 8, T. 19 N., R. 4 E.	Jas. Belcher			do		3,400	Yes	Do.
80	do	do	Sec. 17, T. 19 N., R. 4 E.	do			Large		3,400	Yes	Do.
81	do	do	Sec. 6, T. 19 N., R. 4 E.	Jas. D. Young			do	Limestone	3,500	Yes	Do.

Partial list of springs of Great Falls region, Montana—Continued.

No.	County.	Locality.	Township, etc.	Owner.	Temperature	Quantity	Material from which spring issues	Approximate elevation.	Is supply constant?	Use.
					F.			*Feet.*		
82	Cascade	Great Falls	SW. ¼ sec. 7, T. 19 N., R. 4 E.	Dudley Crothers			Sandstone		Yes	Domestic and stock.
83	do	do	S. ½ sec. 14, T. 19 N., R. 5 E.	M. E. Abernathy			Shale			
84	do	do	Sec. 11, T. 19 N., R. 5 E.	—— Johnston		Medium		4,000	Yes	Do.
85	do	do	NW. ¼ sec. 12, T. 19 N., R. 5 E.	D. E. Johnston		Small			Yes	Stock.
86	do	do	NW. ¼ sec. 7, T. 19 N., R. 5 E.	J. G. Ernst		Medium				Do.
87	do	Stockett	Sec. 36, T. 19 N., R. 4 E.	Eric Erickson		Small		3,700	Yes	Domestic.
88	do	do	SW. ¼ sec. 27, T. 19 N., R. 4 E.	T. Littlejohn		do	Shale	3,900		
89	do	do	SW. ¼ sec. 33, T. 19 N., R. 4 E.	John Edstrom			do	3,900		Stock.
90	do	do	NE. ¼ sec. 31, T. 19 N., R. 4 E.	L. R. Howard		Small			Yes	Domestic and stock.
91	do	do	Sec. 25, T. 19 N., R. 5 E.	T. E. Kent		Medium	Sandstone		Yes	Do.
92	do	do	NW. ¼ sec. 36, T. 19 N., R. 5 E.	W. Turner			do			Do.
93	do	do	SE. ¼ sec. 35, T. 19 N., R. 5 E.	A. Santschi		Medium			Yes	Do.
94	do	do	Sec. 24, T. 19 N., R. 5 E.	S. C. King					Yes	Stock.
95	do	do	NE. ¼ sec. 27, T. 19 N., R. 5 E.	D. Lane		Medium			Yes	
96	do	do	SW. ¼ sec. 22, T. 19 N., R. 5 E.	do						
97	do	do	NE. ¼ sec. 2, T. 18 N., R. 4 E.	Benj. Stephens		Medium				Domestic and stock.
98	do	do	NE. ¼ sec. 22, T. 18 N., R. 4 E.	G. H. Lindh		Small	Sandstone	3,800	Yes	Do.
99	do	do	Sec. 28, T. 18 N., R. 4 E.	N. Frank		Medium	do	3,850	Yes	Do.
100	do	do	SE. ¼ sec. 26, T. 18 N., R. 4 E.	John Gillis		Small	do	4,750	Yes	Domestic.
101	do	do	do	do		Medium	do	4,750	Yes	Stock.
102	do	do	NW. ¼ sec. 15, T. 18 N., R. 4 E.	Ed. Connelly		Small	do	3,800		Domestic and stock.
103	do	do	Sec. 25, T. 18 N., R. 4 E.	C. Cavanaugh		do	do		Yes	Stock.
104	do	do	SE. ¼ sec. 14, T. 18 N., R. 4 E.	Davale Culberson		Medium	Alluvium	4,450	Yes	Domestic and stock.
105	do	do	NE. ¼ sec. 25, T. 18 N., R. 5 E.	Eric Lindquist		do			Yes	Domestic.
106	do	do	SW. ¼ sec. 6, T. 18 N., R. 5 E.	Cottonwood Coal Co.		do		3,600	Yes	
107	do	do	Sec. 7, T. 18 N., R. 5 E.	Joe Sarzin		do		3,700	Yes	Domestic and stock.
108	do	do	Sec. 19, T. 18 N., R. 5 E.	Joe Kornowski		do				Do.
109	do	do	NE. ¼ sec. 2, T. 18 N., R. 5 E.	A. Keels		Small	Sandstone		Yes	Do.
110	do	do	SW. ¼ sec. 2, T. 17 N., R. 4 E.	J. H. Betts		Medium	do	4,950	Yes	Do.
111	do	do	SE. ¼ sec. 2, T. 17 N., R. 4 E.	J. P. Heber		Large		5,000	Yes	
112	do	do	Sec. 1, T. 17 N., R. 4 E.	J. O. Selstrom		Small		5,000	No	Domestic.
113	do	do	do	do		Large		5,000	Yes	Stock.
114	do	do	Sec. 17, T. 17 N., R. 4 E.	L. Herbolsheimer		Small		4,925	Yes	Domestic and stock.
115	do	do	NE. ¼ sec. 21, T. 17 N., R. 4 E.	Herman Johnson		Medium		5,000	Yes	Do.
116	do	do	NW. ¼ sec. 29, T. 17 N., R. 4 E.	John Pilgrim		Small		5,000	Yes	Do.
117	do	do	Sec. 17, T. 17 N., R. 4 E.	Edwin Meisenbach		do		5,000	Yes	Do.
118	do	do	SW. ¼ sec. 4, T. 17 N., R. 4 E.	Wm. Kirby		do	Sandstone		Yes	Do.
119	do	do	Sec. 9, T. 17 N., R. 4 E.	do		do	do		Yes	Do.
120	do	do	NE. ¼ sec. 35, T. 21 N., R. 6 E.	P. P. Buchanan		do			No	Domestic.
121	do	do	Sec. 2, T. 20 N., R. 6 E.	V. P. Carr		Large			Yes	Stock.
122	do	do	Sec. 35, T. 20 N., R. 6 E.	P. P. Buchanan						
123	do	do	NW. ¼ sec. 33, T. 20 N., R. 6 E.	Mack Depew	55	Small	Sandstone		Yes	

124	do	do	Sec. 32, T. 19 N., R. 6 E.	E. Turner						Domestic and stock.
125	do	do	NW. ¼ sec. 14, T. 19 N., R. 6 E.	John Wright		Medium			Yes	Domestic.
126	do	do	SW. ¼ sec. 1, T. 19 N., R. 6 E.	W. S. Sifford		do			Yes	Domestic and stock.
127	do	do	NW. ¼ sec. 8, T. 19 N., R. 6 E.	—— Erickson					Yes	Domestic.
128	do	do	NE. ¼ sec. 32, T. 19 N., R. 6 E.	C. Turner		Small			Yes	Do.
129	do	do	SE. ¼ sec. 22, T. 19 N., R. 6 E.	—— Rush		Medium		3,700	Yes	Domestic and stock.
130	do	do	Sec. 5, T. 19 N., R. 6 E.	W. H. Porter		do	Sandstone		Yes	Do.
131	do	do	Sec. 8, T. 19 N., R. 6 E.	G. Erickson		Large		3,800	Yes	Do.
132	do	do	SW. ¼ sec. 3, T. 19 N., R 6 E.	Joe Bogner		Medium		4,300(?)		Do.
133	do	do	NW. ¼ sec. 5, T. 19 N., R. 6 E.	J. B. Burrows		Small		3,900	Yes	Domestic.
134	do	do	NW. ¼ sec. 1, T. 19 N., R. 6 E.	A. Bloom		Medium	Alluvium		Yes	Domestic and stock.
135	do	do	NW. ¼ sec. 36, T. 19 N., R. 6 E.	A. H. McMillan		Small			Yes	Do.
136	do	do	NE. ¼ sec. 35, T. 19 N., R. 6 E.	Edgar Mann		do			Yes	Stock.
137	do	do	Sec. 36, T. 18 N., R. 6 E.	C. Siegling		Medium				
138	do	do	NW. ¼ sec. 19, T. 18 N., R. 6 E.	J Eckerson						
139	do	do	NW. ¼ sec. 19, T. 18 N., R. 6 E.	J. Shannon		Small				
140	do	do	Sec. 19, T. 18 N., R. 6 E.	J. F. Irwin		Medium			Yes	Domestic and stock.
141	do	do	Sec. 2, T. 18 N., R. 6 E.	S. S. Crane	54		Sandstone		No	Stock.
142	do	do	SW. ¼ sec. 3, T. 18 N., R. 6 E.	do	55	Small	Alluvium			
143	do	do	NE. ¼ SE. ¼ sec. 22, T. 18 N., R. 6 E.	Neel Creek Cattle Co.	52				Yes	Stock, domestic, and irrigation.
144	do	do	NE. ¼ NE. ¼ sec. 27, T. 18 N., R. 6 E.	do			Sandstone			
145	do	do	NE. ¼ NE. ¼ sec. 33, T. 18 N., R. 6 E.	O. V. Jacobs	46		do			
146	do	do	do	do	46					
147	do	do	SE. ¼ sec. 13, T. 18 N., R. 6 E.	J. Wiegand			Sandstone			Domestic and stock.
148	do	do	do	do		Small				Irrigation.
149	do	do	SE. ¼ sec. 24, T. 18 N., R. 6 E.	N. Neumeyer	47	Medium				Domestic.
150	do	do	NW. ¼ sec. 18, T. 18 N., R. 7 E.	C. Ashewert		do	Sandstone	3,700	Yes	Domestic and stock.
151	do	do	SE. ¼ SE. ¼ sec. 30, T. 18 N., R. 7 E.	F. J. Ober		do	do	3,800	Yes	Stock.
152	do	do	SW. ¼ sec. 31, T. 18 N., R. 7 E.	A. Albright		do				Do.
153	do	do	Sec. 27, T. 18 N., R. 7 E.	J. W. Blythe						Irrigation.
154	do	do	NE. ¼ sec. 6, T. 18 N., R. 7 E.	John Hunter					Yes	Domestic.
155	do	do	NW. ¼ SW. ¼ sec. 8, T. 18 N. R. 7 E.	T. D. Joscelyn		Medium		3,800	Yes	Domestic and stock.
156	do	do	do	do		do			Yes	Stock.
157	do	do	SW. ¼ SW. ¼ sec. 8, T. 18 N., R. 7 E.	do		Small			Yes	Do.
158	do	do	SE. ¼ SW. ¼ sec. 8, T. 18 N., R. 7 E.	do		do			Yes	Do.
159	do	do	NW. ¼ SW. ¼ sec. 16, T. 18 N. R. 7 E.	W. B. S. Armstrong		do			Yes	Do.
160	do	do	SW. ¼ SW. ¼ sec. 16, T. 18 N., R. 7 E.	do		do			Yes	Do.
161	do	do	SE. ¼ sec. 16, T. 18 N., R. 7 E.	do		Medium			Yes	Do
162	do	do	NW. ¼ SW. ¼ sec. 22, T. 18 N., R. 7 E	do		do			Yes	Do.
163	do	do	NE. ¼ SW. ¼ sec. 22, T. 18 N., R. 7 E.	P. P. Rector		do			Yes	Domestic, stock, and garden.
164	do	do	NE. ¼ SE. ¼ sec. 34, T. 18 N., R. 7 E.	J. W. Blythe		do			Yes	Stock.

Partial list of springs of Great Falls region, Montana—Continued.

No.	County.	Locality.	Township, etc.	Owner.	Temperature.	Quantity.	Material from which spring issues.	Approximate elevation.	Is supply continuous?	Use.
					°F.			Feet.		
165	Cascade	Stockett	SE. ¼ SE. ¼ sec. 34, T. 18 N., R. 7 E.	J. W. Blythe		Medium			Yes	Stock.
166	do	do	NE. ¼ NE. ¼ sec. 34, T. 18 N., R. 7 E.	do		do			Yes	Domestic and stock.
167	do	do	NW. ¼ SW. ¼ sec. 27, T. 18 N., R. 7 E.	do		do			Yes	Domestic.
168	do	do	NW. ¼ sec. 21, T. 18 N., R. 7 E.	T. Armstrong		do	Sandstone	3,900	Yes	Domestic and stock.
169	do	do	NW. ¼ NW. ¼ sec. 10, T. 18 N., R. 7 E.	G. W. Blake		Small		4,050	Yes	Domestic.
170	do	do	SE. ¼ NW. ¼ sec. 10, T. 18 N., R. 7 E.	do		do		4,050	Yes	Do.
171	do	do	SW. ¼ SE. ¼ sec. 4, T. 18 N., R. 7 E.	F. Falls		Medium		4,025	Yes	Stock.
172	do	do	SW. ¼ SW. ¼ sec. 4, T. 18 N., R. 7 E.	do		Small			Yes	Domestic and stock.
173	do	do	SW. ¼ NW. ¼ sec. 4, T. 18 N., R. 7 E.	J. Ham		Medium			Yes	Domestic and irrigation.
174	do	do	SE. ¼ NW. ¼ sec. 4, T. 18 N., R. 7 E.	do		Small			Yes	Stock.
175	do	do	NW. ¼ NE. ¼ sec. 4, T. 18 N., R. 7 E.	do		do			Yes	Do.
176	do	do	NW. ¼ sec. 6, T. 18 N., R. 7 E.	Chas. Ashwort		do		3,800	Yes	Domestic and stock.
177	do	do	do	do		do		3,800	Yes	Stock.
178	do	do	do	do		do		3,800	Yes	Do.
179	do	do	NE. ¼ sec. 6, T. 18 N., R. 7 E.	L. Bain		Medium		4,000	Yes	Domestic.
180	do	do	do	do		do		4,000	Yes	Stock.
181	do	do	SW. ¼ sec. 5, T. 18 N., R. 7 E.	D. Maussa		Large			Yes	Do.
182	do	do	SE. ¼ sec. 34, T. 18 N., R. 8 E.	S. Colarchik	48	Medium			Yes	Domestic and stock.
183	do	do	NE. ¼ sec. 34, T. 18 N., R. 8 E.	J. H. Vaskey	50	Small			Yes	Do.
184	do	do	NW. ¼ sec. 35, T. 18 N., R. 8 E.	J. Morrison	47	Large			Yes	Do.
185	do	do	SW. ¼ sec. 23, T. 18 N., R. 8 E.	R. Johnson	51	Medium			Yes	Do.
186	do	do	NW. ¼ sec. 23, T. 18 N., R. 8 E.	A. A. Dawson		Small			No	Stock.
187	do	do	NE. ¼ sec. 22, T. 18 N., R. 8 E.	do	61	do			Yes	Domestic.
188	do	do	SW. ¼ sec. 14, T. 18 N., R. 8 E.	J. Magnuson	51	do			Yes	Stock.
189	do	do	NW. ¼ sec. 14, T. 18 N., R. 8 E.	do		do			Yes	Do.
190	do	do	SW. ¼ sec. 10, T. 18 N., R. 8 E.	W. McGinnis		do			Yes	Do.
191	do	do	NE. ¼ sec. 11, T. 18 N., R. 8 E.	M. Owen		do			Yes	Do.
192	do	do	NE. ¼ sec. 16, T. 18 N., R. 8 E.	F. Brown	49	Medium			Yes	Domestic and stock.
193	do	do	NE. ¼ sec. 13, T. 18 N., R. 8 E.	I. Cameron		Small			No	Stock.
194	do	do	NW. ¼ sec. 26, T. 18 N., R. 8 E.	R. Johnson		Medium			Yes	Do.
195	do	do	NW. ¼ NW. ¼ sec. 21, T. 18 N., R. 8 E.	S. Anderson					Yes	Domestic and stock.

196	do	do	NE. ¼ NW. ¼ sec. 21, T. 18 N., R. 8 E.	do					Yes	Do.
197	do	do	SW. ¼ NE. ¼ sec. 28, T. 18 N., R. 8 E.	R. Williamson		Medium			No	Do.
198	do	do	NE. ¼ SE. ¼ sec. 7, T. 18 N., R. 8 E.	— Klein		Small				Stock.
199	do	do	Sec. 31, T. 18 N., R. 8 E.	A. Owen					Yes	
200	do	do	NW. ¼ sec. 16, T. 18 N., R. 8 E.	P. Brown	50					Domestic and stock
201	do	do	SE. ¼ NE. ¼ sec. 16, T. 18 N., R. 8 E.	do	49	Medium				Do.
202	do	do	SW. ¼ SW. ¼ sec. 29, T. 18 N., R. 8 E.	F. J. Ober		do			Yes	Stock.
203	do	do	NW. ¼ sec. 21, T. 18 N., R. 8 E.	S. Anderson					Yes	Domestic and stock.
204	do	do	NW. ¼ NE. ¼ sec. 31, T. 18 N., R. 8 E.	A. Owen		Small				Domestic.
205	do	do	SE. ¼ NE. ¼ sec. 16, T. 18 N., R. 8 E.	P. Brown	49	Large			Yes	Domestic and stock.
206	do	do	NE. ¼ sec. 2, T. 17 N., R. 7 E.	McConkey Bros		Small			Yes	Stock.
207	do	do	SW. ¼ sec. 1, T. 17 N., R. 7 E.	do		do			Yes	Do.
208	do	do	NW. ¼ sec. 12, T. 17 N., R. 7 E.	do		do			Yes	Do.
209	do	do	SW. ¼ sec. 1, T. 17 N., R. 6 E.	G. W. Goodman						
210	do	do	NW. ¼ NE. ¼ sec. 16, T. 17 N., R. 6 E.	Peter Johnson		Medium				Garden irrigation.
211	do	do	SW. ¼ SE. ¼ sec. 16, T. 17 N., R. 6 E.	do						
212	do	do	SE. ¼ sec. 9, T. 17 N., R. 6 E.	F. Skelton		Medium				
213	do	do	SW. ¼ sec. 31, T. 17 N., R. 7 E.	C. P. Neisman						
214	do	do	SW. ¼ sec. 24, T. 17 N., R. 7 E.	Peterson & Johnson					Yes	
215	do	do	Sec. 22, T. 17 N., R. 7 E.	B. W. Armstrong		Medium	Limestone	5,000		Domestic and stock.
216	do	do	Sec. 15, T. 17 N., R. 7 E.	N. Montag		do				
217	do	do	SW. ¼ sec. 15, T. 17 N., R. 7 E.	J. Holmberg		do				
218	do	do	SE. ¼ sec. 36, T. 17 N., R. 7 E.	Bundy & Henderliden		Small	Shale			
219	do	do	NE. ¼ sec. 36, T. 17 N., R. 7 E.	do		Medium	do			
220	do	do	Sec. 25, T. 17 N., R. 7 E.	do			Limestone			Stock.
221	do	do	Sec. 19, T. 17 N., R. 8 E.	do						
222	do	do	SW. ¼ sec. 36, T. 17 N., R. 7 E.	P. McFee						
223	do	do	SE. ¼ sec. 25, T. 17 N., R. 7 E.	Bundy & Henderliden		Large	Limestone	4,900	Yes	Do.
224	do	do	SE. ¼ sec. 29, T. 17 N., R. 8 E.	Hanson Bros					Yes	
225	do	do	NE. ¼ sec. 32, T. 17 N., R. 8 E.	P. Dotseth			Shale		Yes	
226	do	do	NE. ¼ sec. 19, T. 17 N., R. 8 E.	Bundy & Henderliden		Small		4,500		Do.
227	do	do	NW. ¼ sec. 4, T. 17 N., R. 8 E.	— Peterson	50	Medium	Sandstone		Yes	Do.
228	do	do	Sec. 5, T. 17 N., R. 8 E.	E. R. Huggins					No	
229	do	do	SE. ¼ SE. ¼ sec. 18, T. 17 N., R. 8 E.	McConkey Bros		Medium			Yes	Do.
230	do	do	NE. ¼ sec. 18, T. 17 N., R. 8 E.	Ed. Landy						
231	do	Geyser	SE. ¼ sec. 34, T. 18 N., R. 8 E.	S. Colarchik	49				Yes	
232	do	do	NE. ¼ sec. 34, T. 18 N., R. 8 E.	J. H. Vaskey	52				Yes	
233	do	do	NW. ¼ sec. 35, T. 18 N., R. 8 E.	J. Morrison	47	Large	Sandstone			
234	do	do	SW. ¼ sec. 23, T. 18 N., R. 8 E.	R. Johnson	52		do		Yes	
235	do	do	N. E. ¼ sec. 22, T. 18 N., R. 8 E.	A. A. Dawson		Small				Domestic and stock.
236	do	do	do	do	61	do		4,000	Yes	Do.
237	do	do	SW ¼ sec. 3, T. 18 N., R. 8 E.	C. W. McClay	50	Large			Yes	Not used.

Partial list of springs of Great Falls region, Montana—Continued.

No.	County.	Locality.	Township, etc.	Owner.	Temperature.	Quantity.	Material from which spring issues.	Approximate elevation.	Is supply sufficient?	Use.
					°F.			Feet		
238	Cascade	Geyser	NE. ¼ sec. 11, T. 18 N., R. 8 E.	M. Owen		Small				Stock.
239	do	do	NW. ¼ sec. 14, T. 18 N., R. 8 E.	J. Magnuson	52				Yes	
240	do	do	NE. ¼ sec. 11, T. 18 N., R. 8 E.	Martin Owen		Small	Fine sand			Do.
241	do	do	NW. ¼ sec. 13, T. 18 N., R. 8 E.	Geo. Hay		Medium	Sand rock			
242	do	do	SW. ¼ sec. 10, T. 18 N., R. 8 E.	W. McGinnis		Small			Yes	Do.
243	do	do	SE. ¼ sec. 14, T. 18 N., R. 9 E.	W. Kernaghan	52		Shale		Yes	
244	do	do	NW. ¼ sec. 26, T. 18 N., R. 9 E.	J. Kernaghan		Medium	Sandstone			Do.
245	do	do	SE. ¼ sec. 9, T. 18 N., R. 9 E.	C. J. Ellis	46	do				
246	do	do	SE. ¼ sec. 13, T. 18 N., R. 9 E.	J. Strong		Small			Yes	
247	do	do	SE. ¼ sec. 13, T. 18 N., R. 9 E.	J. Armstrong		do			Yes	Do.
248	do	do	SE. ¼ SE. ¼ sec. 9, T. 18 N., R. 9 E.	C. J. Ellis	46	Medium		4,100	Yes	Domestic, stock, and irrigation.
249	do	do	Sec. 12, T. 18 N., R. 9 E.	S. C. Philbrick	48	do		4,200	Yes	Do.
250	do	do	SE. ¼ sec. 20, T. 18 N., R. 9 E.	D. Rankin						
251	do	do	NW. ¼ sec. 36, T. 18 N., R. 9 E.	School section		Medium			Yes	Stock.
252	do	do	SE. ¼ sec. 16, T. 18 N., R. 9 E.	J. B. Lone		do			Yes	Do.
253	do	do	SE. ¼ sec. 15, T. 18 N., R. 9 E.	J. Kernaghan		Small			Yes	Domestic and stock.
254	do	do	SW. ¼ sec. 13, T. 18 N., R. 9 E.	do		do			Yes	Stock.
255	do	do	Sec. 32, T. 18 N., R. 10 E.	J. R. Long						
256	do	do	SW. ¼ sec. 17, T. 18 N., R. 10 E.	J. Keto	15	Small			Yes	Domestic.
257	do	do	NE. ¼ sec. 3, T. 17 N., R. 8 E.	—— Larson		Medium		3,800	Yes	Stock and garden.
258	do	do	SW. ¼ sec. 3, T. 17 N., R. 8 E.	C. W. McClay	48	do	Sandstone	3,700	Yes	
259	do	do	SE. ¼ sec. 11, T. 17 N., R. 8 E.	W. A. Nelson	54		do			Stock.
260	do	do	NE. ¼ sec. 14, T. 17 N., R. 8 E.	do	55	Medium				
261	do	do	NE. ¼ SE. ¼ sec. 18, T. 17 N., R. 9 E.	G. L. Lee	54	Small			No	Do.
262	do	do	NW. ¼ SE. ¼ sec. 18, T. 17 N., R. 9 E.	do	54	do			No	Do.
263	do	do	SW. ¼ SE. ¼ sec. 18, T. 17 N., R. 9 E.	do	54	do			No	Do.
264	do	do	NE. ¼ SE. ¼ sec. 27, T. 17 N., R. 9 E.	S. McAllister	49	Medium			Yes	Do.
265	do	do	NE. ¼ SW. ¼ sec. 26, T. 17 N., R. 9 E.	do	47	do			Yes	Do.
266	do	do	SW. ¼ NE. ¼ sec. 35, T. 17 N., R. 9 E.	G. Okerman	45	Large			Yes	Domestic and stock.
267	do	do	NW. ¼ SE. ¼ sec. 25, T. 17 N., R. 9 E.	S. McAllister	44	Medium			Yes	Do.
268	do	do	NW. ¼ sec. 10, T. 17 N., R. 9 E.	H. P. Schumacher		Small			No	Stock.
269	do	do	do	do	52	do			Yes	Do.
270	do	do	SE. ¼ sec. 27, T. 17 N., R. 9 E.	S. McAllister	49	Medium				Do.
271	do	do	NE. ¼ sec. 35, T. 17 N., R. 9 E.	G. Okerman	47	do			Yes	Domestic and stock.

272	do	do	SW. ¼ sec. 26, T. 17 N., R. 9 E.	S. McAllister	47	do				
273	do	do	SE. ¼ sec. 25, T. 17 N., R. 9 E.	do	47					Do.
274	do	do	NE. ¼ sec. 19, T. 17 N., R. 9 E.	G. L. Lee		Medium			Yes	Do.
275	do	do	SW. ¼ sec. 8, T. 17 N., R. 10 E.	J. B. Long		do			Yes	Do.
276	do	do	SE. ¼ sec. 19, T. 17 N., R. 10 E.	P. O'Hara	45	do		4,300	Yes	Domestic, stock, and irrigation.
277	do	do	NW. ¼ sec. 20, T. 17 N., R. 10 E.	J. H. Skelton	41	do		4,700	Yes	Do.
278	do	do	SE. ¼ sec 17, T. 17 N., R. 10 E.	J. Keto	59	Small		4,200	Yes	Domestic.
279	do	do	SE. ¼ sec. 20, T. 17 N., R. 10 E.	P. O'Hara	48	Medium		4,300		
280	do	do	NW. ¼ sec. 18, T. 17 N., R. 10 E.	L. Waldeland	49				Yes	
281	do	do	SE. ¼ sec. 3, T. 16 N., R. 9 E.	John Downey					Yes	
282	do	do	NE. ¼ sec. 9, T. 16 N., R. 9 E.	Peter Van	48	Small				
283	do	do	NE. ¼ sec. 17, T. 16 N., R. 9 E.	L. Bergeron	44	Large			Yes	
284	do	do	W. ½ sec. 17, T. 16 N., R. 9 E.	D. Naud					Yes	
285	do	do	SW. ¼ sec. 5, T. 16 N., R. 9 E.	Delphas LeBlanc			Limestone			
286	do	do	NE. ¼ sec. 5, T. 16 N., R. 9 E.	do	48					Do.
287	do	do	NE. ¼ sec. 14, T. 16 N., R. 9 E.	Peter Van	48	Small				
288	do	do	SW. ¼ sec. 8, T. 16 N., R. 9 E.	O. Swanson			Sandstone		No	
289	do	do	SW. ¼ sec. 9, T. 16 N., R. 9 E.	do	48	Small	do		Yes	Domestic and stock.
290	do	do	NE. ¼ sec. 2, T. 16 N., R. 9 E.	J. M. Walters		do	do		Yes	Do.
291	do	do	Sec. 4, T. 16 N., R. 10 E.	T. Shannon	52	do				Do.
292	do	do	SE. ¼ NE. ¼ sec. 4, T. 16 N., R. 10 E.	do	46	Medium	Drift			Irrigation and stock.
293	do	do	SW. ¼ NW. ¼ sec. 4, T. 16 N., R. 10 E.	do	49					Irrigation.
294	do	do	SW. ¼ sec. 19, T. 16 N., R. 10 E.	P. O'Hara	45	Medium	Limestone			
295	do	do	SW. ¼ sec. 4, T. 16 N., R. 10 E.	J. H. Skelton	42	do	do			Do.
296	do	do	SW. ¼ sec. 34, T. 16 N., R. 10 E.	H. G. Burgess	46		Drift			
297	do	do	SW. ¼ sec. 20, T. 16 N., R. 10 E.	J. H. Skelton	42	Medium			Yes	Domestic and stock.
298	do	Stanford	SW. ¼ sec. 25, T. 17 N., R. 10 E.	Thos. Higgins	51	do			Yes	
299	do	do	do	do		Small				
300	do	do	do	do		do	Limestone			
301	Fergus	do	Sec. 11, T. 17 N., R. 11 E.	Bower Bros		do		4,100	Yes	Domestic.
302	do	do	SE. ¼ NE. ¼ sec. 33, T. 17 N., R. 11 E.	do						
303	Cascade	do	Secs. 1 and 2, T. 16 N., R. 10 E.	D. Butterfield	48	Small			No	
304	do	do	do	do	45	Medium			Yes	
305	do	do	Secs. 1 and 2, T. 16 N., R. 10 E.	do	44	do			Yes	
306	do	do	NE. ¼ sec. 13, T. 16 N., R. 10 E.	Pool Ranch	46	Small				Do.
307	do	do	NW. ¼ sec. 25, T. 16 N., R. 10 E.	A. V. Cheney	52	Medium				
308	do	do	NE. ¼ NE. ¼ sec. 25, T. 16 N., R. 10 E.	First National Bank	50	Small			Yes	Stock.
309	do	do	SW. ¼ sec. 34, T. 16 N., R. 10 E.	—— Burgess	47	Medium			Yes	Domestic and stock.
310	do	do	NW. ¼ NW. ¼ sec. 13, T. 16 N., R. 10 E.	First National Bank		do			Yes	Stock (?).
311	do	do	SW. ¼ sec. 25, T. 16 N., R. 10 E.	T. Higgins	51	do			Yes	Stock.
312	Fergus	do	NE. ¼ sec. 24, T. 16 N., R. 11 E.	Bower Bros		do			Yes	Do.
313	do	do	SW. ¼ sec. 13, T. 16 N., R. 11 E.	P. Westfall		Small			Yes	
314	do	do	NW. ¼ sec. 13, T. 16 N., R. 11 E.	R. Skelton	48	Medium		4,400		Domestic and irrigation.
315	do	do	SW. ¼ sec. 12, T. 16 N., R. 11 E.	do	48					Do.

Partial list of springs of Great Falls region, Montana—Continued.

No.	County.	Locality.	Township, etc.	Owner.	Temperature.	Quantity.	Material from which spring issues.	Approximate elevation.	Is supply continuous?	Use.
					°F.			Feet.		
316	Fergus	Stanford	SW. ¼ NE. ¼ sec. 13, T. 16 N., R. 11 E.	E. F. Tuttle						Irrigation.
317	do	do	SE. ¼ NE. ¼ sec. 13, T. 16 N., R. 11 E.	do	52	Medium			Yes	
318	do	do	SW. ¼ sec. 25, T. 16 N., R. 11 E.	G. H. Ketchner		Large				
319	do	do	Sec. 35, T. 16 N., R. 11 E.	Fisher ranch		Medium			Yes	
320	do	do	NE. ¼ sec. 7, T. 16 N., R. 11 E.	Bower Bros	47	do	Sandstone			
321	do	do	NE. ¼ sec. 31, T. 16 N., R. 12 E.	S. S. Hobson	55	Small				
322	Cascade	do	SE. ¼ NE. ¼ sec. 2, T. 15 N., R. 10 E.	—— Butterfield	45	do		4,000	Yes	Domestic and stock.
323	Fergus	do	Sec. 10, T. 15 N., R. 11 E.	Bower Bros	47	Medium		2,000		Domestic, stock, and irrigation.
324	do	do	NE. ¼ sec. 3, T. 15 N., R. 11 E.	do	46	Large			Yes	Domestic and stock
325	do	do	SE. ¼ sec. 24, T. 15 N., R. 11 E.	J. Jehnick	46	Medium			Yes	Domestic.
326	do	do	SW. ¼ sec. 24, T. 15 N., R. 11 E.	do	46	Small			Yes	Stock
327	do	do	SW. ¼ sec. 30, T. 15 N., R. 12 E.	Sage Creek Sheep Co.		do				Do.
328	do	do	SE. ¼ sec. 30, T. 15 N., R. 12 E.	do		Medium				Do.
329	do	do	SW. ¼ sec. 31, T. 15 N., R. 12 E.	do		do				Do.
330	do	do	SE. ¼ sec. 32, T. 15 N., R. 12 E.	do		do				Do.
331	do	do	NW. ¼ sec. 26, T. 15 N., R. 12 E.	do		do				Do.
332	do	do	NW. ¼ sec. 23, T. 15 N., R. 12 E.	do		Small				Do.
333	do	do	SW. ¼ sec. 4, T. 15 N., R. 12 E.	A. T. Kach	49	Medium	Sandstone			

Partial list of wells of Great Falls region, Montana.

No.	County.	Locality.	Township, etc.	Owner.	Depth.	Date completed.	Quality of water.	Is supply continuous?	How obtained at surface.	Geologic formation.	Use.
					Feet.						
1	Teton	Choiteau	Sec. 30, T. 25 N., R. 5 W.	Nicolas Tuttle	130			Yes			Domestic and stock
2	do	do	Sec. 20, T. 25 N., R. 5 W.	do	165	1902		Yes			Do.
3	do	do	SE. ¼ sec. 5, T. 25 N., R. 5 W.	Lewis A. Savik	40	1899	Slightly hard.	Yes			Do.
4	do	do	SE. ¼ sec. 28, T. 25 N., R. 4 W.	Bollerud Bros.	13	1898	Hard				Do.
5	do	do	SW. ¼ sec. 24, T. 25 N., R. 4 W.	Olaf Lindseth	13	1896	do				Do.
6	do	do	SE. ¼ sec. 13, T. 25 N., R. 4 W.	J. Johnson	9	1905	Slightly hard.	Yes		Gravel	Do.

7	do	do	NE. ¼ sec. 6, T. 24 N., R. 5 W.	Earl Yeager	65		Hard	Yes			Do.
8	do	do	SW. ¼ sec. 3, T. 24 N., R. 4 W.	Abrem Broere	40			No water		Shale	
9	do	do	NW. ¼ sec. 2, T. 24 N., R. 4 W.	W. N. Van Der Riet.	80			No water			
10	do	do	SW. ¼ sec. 19, T. 24 N., R. 4 W.	C. E. Moore	30		Very hard	Yes		Shale	Do.
11	do	do	SW. ¼ sec. 5, T. 24 N., R. 4 W.	W. W. Gamble	12		Slightly hard.	Yes		Gravel	Domestic.
12	do	do	NE. ¼ sec. 5, T. 24 N., R. 4 W.	—— Carlson	12	1894	Hard			Shale	Domestic and stock.
13	do	do	SW. ¼ sec. 24, T. 23 N., R. 4 W.	Chris Lindseth	47					Shale and gravel.	
14	do	do	NW. ¼ sec. 13, T. 22 N., R. 4 W.	J. Thom	9		Fair	Yes			
15	Lewis and Clark	Augusta	NE. ¼ sec. 1, T. 20 N., R. 6 W.	Mrs. C. C. Woods	24		Good	Yes			Domestic.
16	do	do	NE. ¼ sec. 7, T. 20 N., R. 5 W.	J. S. Lytle	8		Alkaline	Yes			Irrigation.
17	do	do	SE. ¼ sec. 9, T. 20 N., R. 5 W.	P. Bickel	34		do				Stock.
18	do	do	Sec. 1, T. 20 N., R. 5 W	Mrs. Fullberg	20		Good	Yes		Alluvium	Domestic and stock.
19	do	do	Sec. 7, T. 20 N., R. 4 W	H. C. Reilz	15		Hard	Yes		do	
20	do	do	Sec. 8, T. 20 N., R. 4 W	H. J. Riedling	22		Alkaline	Yes		do	
21	do	do	Sec. 5, T. 20 N., R. 4 W	S. Eder	12						
22	Teton	Hepler	SE. ¼ sec. 29, T. 22 N., R. 3 W.	Cole Bros	10		Good	Yes	Windmill		Stock.
23	do	do	NE. ¼ sec. 32, T. 22 N., R. 3 W.	do	16		do	Yes			
24	Cascade	do	NE. ¼ sec. 31, T. 22 N., R. 3 W.	E. G. Kufus	20		do	No		Shale	
25	do	do	SE. ¼ sec. 31, T. 22 N., R. 3 W.	J. C. Kufus	23		do	Yes			
26	do	do	SE. ¼ sec. 35, T. 22 N., R. 3 W.	F. C. Krucks	40		do	Yes		Shale	
27	do	do	SW. ¼ sec. 35, T. 22 N., R. 3 W.	do	35		do				
28	Teton	do	NW. ¼ sec. 30, T. 22 N., R. 2 W.	Z. Zimmerman	75	1903	Hard	Yes			
29	Cascade	do	NE. ¼ sec. 5, T. 21 N., R. 3 W.	—— Flowerree	15			Yes		Sandstone	
30	do	do	SW. ¼ sec. 20, T. 21 N., R. 2 W.	Cascade Land Co	100			No	Windmill		Stock.
31	do	do	SE. ¼ sec. 23, T. 20 N., R. 3 W.	J. F. Johnson	18		Alkaline			Alluvium	
32	do	do	SW. ¼ sec. 10, T. 20 N., R. 3 W.	P. B. Fox	20		Fair				Do.
33	do	do	NW. ¼ sec. 22, T. 20 N., R. 3 W.	T. Seaquist	71	1902		Yes			Domestic.
34	do	do	NW. ¼ sec. 23, T. 20 N., R. 3 W.	do	15						Do.
35	do	do	NW. ¼ sec. 21, T. 20 N., R. 3 W.	G. LaRue	11		Good				
36	do	do	SE. ¼ sec. 4, T. 20 N., R. 3 W.	H. Olson	17		do				
37	do	do	NW. ¼ sec. 4, T. 20 N., R. 3 W.	—— Flowerree	65		do				
38	do	do	NE. ¼ sec. 10, T. 20 N., R. 3 W.	D. B. Todd	20		do			Alluvium	
39	do	do	Sec. 33, T. 20 N., R. 2 W	Sun River Land and Stock Co.	10						Domestic.
40	do	do	NE. ¼ sec. 31, T. 20 N., R. 2 W.	do					Windmill		Stock.
41	do	Dutton	Sec. 4, T. 24 N., R. 1 W	do	108			Yes			
42	do	do	Sec. 22, T. 23 N., R. 1 W	do	108			No			
43	do	do	do	do	110						
44	do	Sun River	SW. ¼ sec. 29, T. 22 N., R. 1 W	do	20			Yes	Windmill	Alluvium	
45	do	do	NE. ¼ sec. 31, T. 21 N., R. 1 W.	Noble Bros	85		Alkaline				
46	do	do	SE. ¼ sec. 30, T. 21 N., R. 1 W.	D. Davies	15		do	Yes			Do.
47	do	do	SW. ¼ sec. 30, T. 21 N., R. 1 W.	Ford ranch	25		do				Do.
48	do	do	NE. ¼ sec. 34, T. 21 N., R. 1 W	M. L. Strong	63		Soft				
49	do	do	NW. ¼ sec. 36, T. 21 N., R. 1 W.	J. C. Adams	80		Hard				
50	do	do	NW. ¼ sec. 2, T. 20 N., R. 1 W.	E. C. Blossom	96		Alkaline				
51	do	do	NE. ¼ sec. 25, T. 21 N., R. 1 W.	Gouch Bros	15						
52	do	do	NE. ¼ sec. 27, T. 21 N., R. 1 W.	B. Thomas	10					Alluvium	
53	do	do	Sec. 12, T. 20 N., R. 1 E	—— Hollarf	140					Sandstone	
54	do	do	Sec. 14, T. 20 N., R. 1 E		128						
55	do	do	do	—— Swager	90					Sandstone	

Partial list of wells of Great Falls region, Montana—Continued.

No.	County.	Locality.	Township, etc.	Owner.	Depth (feet).	Date completed.	Quality of water.	Is supply continuous?	How obtained at surface.	Geologic formation.	Use.
56	Cascade	Sun River	NE. ¼ sec. 13, T. 19 N., R. 2 W.	Toman Bros.	40					sandstone	
57	do	do	NW. ¼ sec. 12, T. 19 N., R. 1 W.	Ed. Bull	35						Stock.
58	do	do	NE. ¼ sec. 22, T. 19 N., R. 1 W.	D. E. Rease	30						
59	do	do	NW. ¼ sec. 21, T. 19 N., R. 1 W.	E. A. Weigand	40		Alkaline				Do.
60	do	do	SE. ¼ sec. 35, T. 18 N., R. 1 W.	H. F. Montag	15	1890	Hard	Yes			Domestic and stock.
61	do	do	Sec. 13, T. 18 N., R. 1 W.	W. Bochna	18						
62	do	do	do	do	30						
63	do	do	Sec. 26, T. 18 N., R. 1 W.	Cascade Waterworks.	78		Hard				Domestic.
64	do	do	Sec. 35, T. 18 N., R. 1 W.	do	25		do				
65	do	do	do	H. Schrameck	18		do		Windmill	Alluvium.	
66	do	do	SE. ¼ sec. 35, T. 18 N., R. 1 W.	do	17	1882	do	Yes			Domestic, stock, irrigation, and manufacturing.
67	do	do	NW. ¼ sec. 30, T. 18 N., R. 1 E.	Benj. Rumney	20	1890	do	Yes	Pump		Domestic and stock.
68	do	do	NW. ¼ sec. 1, T. 18 N., R. 1 E.	James Travis	12	1889	Iron	Yes	do		Domestic, stock, and irrigation.
69	do	do	Sec. 24, T. 18 N., R. 1 E.	Sam Jones	30		Soft				Domestic.
70	do	do	Sec. 8, T. 17 N., R. 1 E.	Sam Kelly	30		do	Yes	Pump		Domestic and stock.
71	do	do	SE. ¼ sec. 8, T. 17 N., R. 1 E.	G. H. Crum	65	1886	Hard		do		Do.
72	do	do	T. 17 N., R. 1 E.	Aug. Wedsworth	16	1895	do	Yes	do		Domestic.
73	do	do	Sec. 29, T. 19 W., R. 2 E.	J. Ferguson	276			No water			
74	do	do	Sec. 29, T. 19 N., R. 2 E.	T. C. King	80			Yes			
75	do	do	Sec. 28, T. 19 N., R. 2 E.	G. S. Ferguson	50			Yes			
76	do	do	Sec. 26, T. 19 N., R. 2 E.	Sanden T. Hops	50		Soft		Windmill		
77	do	do	Sec. 31, T. 19 N., R. 3 E.	Prudle	68			No			Do.
78	do	do	Sec. 29, T. 19 N., R. 3 E.	A. Hickey	72		Good				Domestic, stock, and irrigation.
79	do	Truly	Sec. 21, T. 18 N., R. 2 E.	—— McLaughlin	10		Hard				
80	do	do	do	—— Cummins			do				
81	do	do	SW. ¼ sec. 16, T. 18 N., R. 2 E.	Cranston	65		Alkaline	No			
82	do	do	Sec. 21, T. 18 N., R. 2 E.	Perry	8		do				
83	do	do	Sec. 17, T. 18 N., R. 2 E.	J. A. Perrine	17		Hard				
84	do	do	do	do	22		do				
85	do	do	do	do	125		do		Bucket		
86	do	do	Sec. 18, T. 18 N., R. 2 E.	J. W. Perrine	40	1902	do				
87	do	do	Sec. 17, T. 18 N., R. 2 E.	W. G. Stone	23	1905		Yes			Domestic and stock.
88	do	do	Sec. 7, T. 18 N., R. 2 E.	J. S. Ferguson	35		Hard	Yes			Stock.
89	do	do	Sec. 8, T. 18 N., R. 2 E.	R. Richardson	12	1905					Domestic and stock.
90	do	do	Sec. 5, T. 18 N., R. 2 E.	Hughes	17						
91	do	do	do	do	16			No			
92	do	do	NE. ¼ sec. 28, T. 18 N., R. 2 E.	J. H. Daly	225			No water			
93	do	do	do	do	75		Soft	Yes			

94	do	do	Sec. 3, T. 18 N., R. 2 E.	W. Misolf	10		Hard					
95	do	do	Sec. 28, T. 18 N., R. 2 E.	F. Johnson	20							
96	do	do	Sec. 6, T. 18 N., R. 2 E.	R. Oliver	20		Hard	No				Domestic
97	do	do	NW. ¼ sec. 5, T. 18 N., R. 2 E.	D. Lynne	80			No				
98	do	do	SW. ¼ sec. 5, T. 18 N., R. 2 E.	— Patton	20		Alkali					
99	do	do	Sec. 3, T. 18 N., R. 2 E.	H. S. Curtis	108		Good				Sandstone	
100	do	do	NW. ¼ sec. 3, T. 18 N., R. 2 E.	D. Lynne	102		Hard				do	
101	do	do	Sec. 12, T. 18 N., R. 3 E.	— Evans	20		Good	Yes				
102	do	do	NE. ¼ sec. 28, T. 18 N., R. 3 E	— Hinsoe	222		Hard					
103	do	do	NW. ¼ sec. 23, T. 18 N., R. 3 E.	M. C. Cumber	27						Shale	
104	do	do	Sec. 21, T. 18 N., R. 3 E.	P. Linquist	60			Yes			do	
105	do	do	SE. ¼ sec. 20, T. 18 N., R. 3 E.	C. Hanson	215							
106	do	do	Sec. 9, T. 18 N., R. 3 E.	— Bisson	14		Hard	No				
107	do	do	Sec. 10, T. 18 N., R. 3 E.	— Hale	16				Pump			
108	do	do	Sec. 9, T. 18 N., R. 3 E.	R. Skinner	132						Sandstone	
109	do	do	SW. ¼ SW. ¼ sec. 2, T. 17 N., R. 2 E.	T. J. S. Wingley	18						Shale	
110	do	do	SE. ¼ NE. ¼ sec. 4, T. 17 N., R. 2 E.	V. P. Carr	12		Hard					
111	do	do	do	do	22		do					
112	do	do	NW. ¼ sec. 19, T. 17 N., R. 2 E.	J. Carlile	20			No water				
113	do	do	NW. ¼ sec. 28, T. 17 N., R. 2 E.	Sutton Bros	9		Good					
114	do	do	Sec. 2, T. 17 N., R. 2 E.	— Vesley	26		do					
115	do	do	SW. ¼ sec. 4, T. 17 N., R. 3 E.	Stin Bros	24		Hard	Yes				Domestic.
116	do	do	do	T. Splain	8						Alluvium	Stock and irrigation.
117	do	do	do	J. Marxer	102			No				
118	do	do	do	do	35		Slightly hard.	Yes	Pump		Red shale and gray sandy limestone.	Domestic and stock,
119	do	do	do	do	22			Yes	Windmill			Irrigation.
120	do	do	SE. ¼ sec. 14, T. 17 N., R. 3 E.	J. Cocren	27			Yes				
121	do	do	NE. ¼ sec. 24, T. 17 N., R. 3 E.	— Knight	65		Good	Yes	Pump			Domestic and stock.
122	do	do	SE. ¼ sec. 24, T. 17 N., R. 3 E.	Geo. Bell	110			Yes	do			Domestic.
123	do	do	SW. ¼ SW. ¼ sec. 24, T. 17 N., R. 3 E.	— Milligan	125			Yes	Windmill			
124	do	do	SE. ¼ NE. ¼ sec. 26, T. 17 N., R. 3 E.	B. Marxer	75			Yes	Pump			Do.
125	do	do	SE. ¼ sec. 22, T. 17 N., R. 3 E.	G. Werl	32		Alkaline	Yes			Sandstone	
126	do	do	Sec. 30, T. 17 N., R. 3 E.	G. A. Colby	21			No water				
127	do	do	do	do	21			Yes				
128	do	do	SW. ¼ sec. 8, T. 17 N., R. 3 E.	Huntsbarger Bros.	10		Soft					
129	do	Great Falls	SW. ¼ sec. 22, T. 20 N., R. 2 E.	A. W Craig	32	1895	Alkaline	Yes				Domestic and stock.
130	do	do	NE. ¼ sec. 29, T. 20 N., R. 2 E.	H. W. Boynton	76	1903	(?)	Yes	Pump			Domestic, stock, and irrigation.
131	do	do	SE. ¼ sec. 22, T. 20 N., R. 2 E.	do	150							
132	do	do	NW. ¼ sec. 24, T. 20 N., R. 2 E.	Eugene J. Dugas	47	1900	Fair	Yes	Pump		Shale	Domestic and stock.
133	do	do	SW. ¼ sec. 2, T. 20 N., R. 2 E.	Wm. Straling	140	1905	Hard	Yes				
134	do	do	SW. ¼ sec. 22, T. 20 N., R. 2 E.	A. W. Craig	40							
135	do	do	do	do	457			No water			Shale	
136	do	do	do	do	32			No				
137	do	do	SE. ¼ sec. 20, T. 20 N., R. 2 E.	do	40							
138	do	do	do	do							Shale	

Partial list of wells of Great Falls region, Montana—Continued.

No.	County.	Locality.	Township, etc.	Owner.	Depth (feet).	Date completed.	Quality of water.	Is supply continuous?	How obtained at surface.	Geologic formation.	Use.
139	Cascade	Great Falls	SE. ¼ sec. 29, T. 20 N., R. 2 E.	A. W. Craig	32						
140	do	do	NE. ¼ sec. 28, T. 20 N., R. 2 E.	do	15		Alkaline				
141	do	do	SE. ¼ sec. 29, T. 20 N., R. 2 E.	do	6						
142	do	do	do	do	6		Alkaline				
143	do	do	Sec. 28, T. 20 N., R. 2 E.	do	15		Hard				
144	do	do	do	McCloud	45		do				
145	do	do	NE. ¼ sec. 34, T. 20 N., R. 2 E.	Stratin	10			Yes			
146	do	do	NW. ¼ sec. 33, T. 20 N., R. 2 E.	do	525			No water			
147	do	do	do	do	90			Yes			
148	do	do	NE. ¼ sec. 23, T. 20 N., R. 2 E.	do	125			No water			
149	do	do	SE. ¼ sec. 35, T. 20 N., R. 2 E.	do	8						Domestic and stock.
150	do	do	SW. ¼ sec. 25, T. 20 N., R. 2 E.	Transon	94		Alkaline	Yes			
151	do	do	SE. ¼ sec. 15, T. 20 N., R. 2 E.	C. K. Giles	57		Good				
152	do	do	NE. ¼ sec. 15, T. 20 N., R. 2 E.	Shobert	12			Yes			
153	do	do	Sec. 19, T. 20 N., R. 2 E.	Cherpeski	91						
154	do	do	Sec. 29, T. 20 N., R. 2 E.	Stewart	76						
155	do	do	Sec. 21, T. 20 N., R. 2 E.	Weber	71		Good				
156	do	do	SW. ¼ sec. 23, T. 20 N., R. 2 E.	Arnold	133						
157	do	do	Sec. 15, T. 20 N., R. 2 E.	Rumbeaugh	76						
158	do	do	Sec. 13, T. 20 N., R. 2 E.	Geerson	51		Good				
159	do	do	Sec. 9, T. 20 N., R. 2 E.	Carruthers	123						
160	do	do	Sec. 22, T. 20 N., R. 2 E.	Boynton	320						
161	do	do	SW. ¼ sec. 17, T. 20 N., R. 3 E.	Peter Dindolad	114	1906	Good	Yes		Shale	Do.
162	do	do	NE. ¼ sec. 30, T. 20 N., R. 3 E.	G. D. Nicolai	61	1904	Hard	Yes			Do.
163	do	do	Sec. 21, T. 20 N., R. 4 E.	P. Gibson	25						
164	do	do	NW. ¼ sec. 22, T. 20 N., R. 4 E.	do	17						
165	do	do	SE. ¼ sec. 20, T. 20 N., R. 4 E.	do	14						
166	do	do	SW. ¼ sec. 27, T. 20 N., R. 4 E.	do	18						
167	do	do	NE. ¼ sec. 32, T. 20 N., R. 4 E.	John Locke	27		Hard				Do.
168	do	do	do	W. H. Mitchell	56	1906	do				Do.
169	do	do	NW. ¼ sec. 31, T. 20 N., R. 4 E.	W. F. Jenkin	9	1893	do				
170	do	do	NE. ¼ sec. 26, T. 20 N., R. 4 E.	Great Falls Meat Co.	126	1904	do	Yes	Windmill	Gravel and clay.	Stock.
171	do	do	SW. ¼ sec. 13, T. 20 N., R. 4 E.	do	300	1895	Very poor				
172	do	do	NE. ¼ sec. 4, T. 20 N., R. 4 E.	do	300	1893	Poor				
173	do	do	NW. ¼ sec. 15, T. 20 N., R. 4 E.	do	165	1893					
174	do	do	SE. ¼ sec. 25, T. 20 N., R. 4 E.	F. Yost	25		Hard		Windmill		Do.
175	do	do	SE. ¼ sec. 26, T. 20 N., R. 4 E.	Lee ranch	4		Good	Yes	do	Alluvium	
176	do	do	NE. ¼ sec. 26, T. 20 N., R. 4 E.	do					do		
177	do	do	SW. ¼ sec. 8, T. 20 N., R. 5 E.	Great Falls Meat Co.	300	1904					
178	do	do	SE. ¼ sec. 32, T. 20 N., R. 5 E.	E. Grieger	10		Soft	Yes		Alluvium	
179	do	do	Sec. 32, T. 20 N., R. 5 E.	do	5						
180	do	do	SW. ¼ sec. 31, T. 20 N., R. 5 E.	do	15		Soft				

181	do	do	NE. ¼ sec. 18, T. 19 N., R. 4 E.	A. Mobray	45	1903	Hard					Domestic and stock.
182	do	do	do	do	160	1905	do					Do.
183	do	do	SE. ¼ sec. 18, T. 19 N., R. 4 E.	John R. Ross	45	1897	do					Domestic.
184	do	Stockett	SW. ¼ sec. 30, T. 19 N., R. 4 E.	R. Skinner	85		do					Domestic and stock.
185	do	Great Falls	NE. ¼ sec. 12, T. 19 N., R. 4 E.	J. G. Ernst	32		do	No				Domestic.
186	do	do	NE. ¼ sec. 12, T. 19 N., R. 5 E.	Ray & Freidrich Sheep Co.	175		Very hard	Yes		Pump		Domestic and stock.
187	do	do	NE. ¼ sec. 9, T. 19 N., R. 5 E.	A. Farling	12		Good	Yes			Sandstone	
188	do	do	SW. ¼ sec. 6, T. 19 N., R. 5 E.	J. Dougherty	12					Pump		Do.
189	do	do	do	do	30			No				
190	do	Stockett	SE. ¼ sec. 27, T. 19 N., R. 4 E.	J. Eisenberg	32		Hard					Do.
191	do	do	NE. ¼ sec. 27, T. 19 N., R. 4 E.	Edmund Dirk	110		Very hard	No				
192	do	do	SW. ¼ sec. 33, T. 19 N., R. 4 E.	John Edstrom	30		Good	No				Domestic.
193	do	do	SW. ¼ sec. 36, T. 19 N., R. 4 E.	C. W. Peterson	40		Hard	No				Do.
194	do	do	Sec. 36, T. 19 N., R. 4 E.	Cottonwood Coal Co	50	1904		No				
195	do	do	Sec. 23, T. 19 N., R. 5 E.	W. E. Abernathy	15			Yes			Sandstone	
196	do	do	do	do	30		Soft					Domestic and stock.
197	do	do	SW. ¼ sec. 35, T. 18 N., R. 4 E.	J. G. Martin	19		Hard					Domestic.
198	do	do	Sec. 21, T. 18 N., R. 4 E.	J. H. Connor	22							Domestic and stock.
199	do	do	Sec 33, T. 18 N., R. 4 E.	J. P. Jones	30	1902	Hard					Do.
200	do	do	NE. ¼ sec. 17, T. 18 N., R. 4 E.	C. Jaeckel	14	1889	do	Yes				Do.
201	do	do	NE ¼ sec. 31, T. 18 N., R. 4 E.	John Steyaerr	30	1905	do				Shale	Do.
202	do	do	NE. ¼ sec. 34, T. 18 N., R. 4 E.	N. J. Wagner	280	1902						
203	do	do	do	do	45		Hard					Domestic.
204	do	do	SW ¼ sec 35, T. 18 N., R. 4 E.	Wm. Kirby	180			Yes		Windmill	Sandstone	
205	do	do	SE. ¼ sec. 25, T 18 N., R. 4 E.	Chester Cavanagh	20	1898	Soft	Yes				Domestic and stock.
206	do	do	Sec. 19, T. 18 N., R. 5 E.	A. Winkle	115	1902	Hard	No				Do.
207	do	do	SE. ¼ sec. 31, T. 18 N., R. 5 E.	Chas. Gereke	205						Shale	
208	do	do	do	J. Mettsh	120	1903	Hard	Yes			Sandstone	Do.
209	do	do	do	—— Marko	200			No				
210	do	do	Sec. 12, T. 18 N., R. 5 E.	John Ross	150	1902	Hard	No			Sandstone	Do.
211	do	do	Sec 14, T. 18 N., R. 5 E.	A. Carlson	65			Yes		Windmill		Stock.
212	do	do	do	do	20		Soft	No				
213	do	do	SW. ¼ sec 14, T. 18 N., R. 5 E.	Penn Bros	35			No				
214	do	do	Sec. 24, T. 18 N., R 5 E.	do	11		Soft	Yes				
215	do	do	NE ¼ sec 26, T 18 N., R. 5 E.	J. M. Mahoney	26		Slightly hard.	Yes				
216	do	do	Sec. 18, T. 18 N., R. 5 E.	J. Knabe	65		Soft	No				Domestic.
217	do	do	do	B. Goethe	15		do	Yes				Domestic and stock.
218	do	do	Sec. 21, T. 18 N., R. 5 E.	Young & Jeffries	9			No				
219	do	do	Sec. 1, T. 18 N., R. 5 E.	O. Romundstad	40	1905	Soft					
220	do	do	Sec. 12, T. 18 N., R. 5 E.	W. Shoop	200			No		Windmill		
221	do	do	Sec. 11, T. 17 N., R. 4 E.	Wellington Gates	50	1905	Soft					Do.
222	do	do	NE. ¼ sec. 2, T. 17 N., R. 4 E.	L. E. Betts	120	1905	Hard					Do.
223	do	do	Sec. 26, T. 20 N., R. 6 E.	J. B. Long	20					Windmill		Do.
224	do	do	NE. ¼ sec. 32, T. 20 N., R. 6 E.	Mack Depew							Sandstone	
225	do	do	SE. ¼ sec. 25, T. 20 N., R. 6 E.	J. A. Demuth	25		Poor					
226	do	do	do	do	50	1906					Blue limestone.	
227	do	do	NE. ¼ sec. 24, T. 20 N., R. 6 E.	J. B. Metzell	25					Steam engine.		
228	do	do	SE. ¼ sec. 13, T. 20 N., R. 6 E.	J. B. Young	12			No		Pump		
229	do	do	NE. ¼ sec. 31 T. 20 N., R. 6 E.	L. F. Leech	14		Poor	No				Do.

Partial list of wells of Great Falls region, Montana—Continued.

No.	County.	Locality.	Township, etc.	Owner.	Depth.	Date completed.	Quality of water.	Is supply continuous?	How obtained at surface.	Geologic formation.	Use.
230	Cascade	Stockett	NW. ¼ sec. 32, T. 20 N., R. 6 E.	J. Dougherty	15						Stock.
231	do	do	Sec. 32, T. 20 N., R. 6 E.	do	20						Do.
232	do	do	NW. ¼ sec. 29, T. 20 N., R. 6 E.	do	20		Soft				
233	do	do	NE. ¼ sec. 18, T. 20 N., R. 7 E.	J. Epperson	20		Hard	Yes			
234	do	do	Sec. 33, T. 20 N., R. 7 E.	Gillette	14	1886	Good	Yes	Pump		Domestic and stock.
235	do	do	NE. ¼ sec. 15, T. 19 N., R. 6 E.	A. H. McMillan	80	1905	do	Yes	do		Do.
236	do	do	SE. ¼ sec. 22, T. 19 N., R. 6 E.	Rush Farm	8		do	Yes	Bucket		Domestic
237	do	do	Sec. 10, T. 19 N., R. 6 E.	Kupperton	20		Hard	Yes			
238	do	do	Sec. 5, T. 19 N., R. 6 E.	W. H. Porter	8		Good	Yes			
239	do	do	do	Henry Kassmier	36		do	Yes			
240	do	do	Sec. 21, T. 19 N., R. 6 E.	C. B. Pyle	35			No			Domestic and stock.
241	do	do	Sec. 14, T. 19 N., R. 6 E.	F. Polultnik	64			No	Bucket		
242	do	do	do	do	80				Windmill		Do.
243	do	do	do	John Wright	16	1900		Yes			
244	do	do	do	do	40						
245	do	do	Sec. 1, T. 19 N., R. 6 E.	W. S. Sifford	25		Poor	No			
246	do	do	Sec. 11, T. 19 N., R. 6 E.	Geo. Togden	27			No			
247	do	do	do	do	175		Good	Yes			
248	do	do	NW. ¼ sec. 3, T. 19 N., R. 6 E.	Jno. and Joe Begner	25						
249	do	do	Sec. 15, T. 19 N., R. 6 E.	Edgar Mann	14	1905	Hard	Yes	Pump		Domestic, stock, and irrigation.
250	do	do	do	do	20	1900	Soft	Yes	do		Do.
251	do	do	NE. ¼ sec. 32, T. 19 N., R. 6 E.	C. Turner	120	1897		No water.			
252	do	do	Sec. 15, T. 19 N., R. 6 E.	A. H. McMillan	80	1905	Soft	Yes	Pump		Domestic and stock.
253	do	do	NW. ¼ sec. 6, T. 19 N., R. 6 E.	S. Dean	14		Slightly hard.	Yes		Alluvium	
254	do	do	Sec. 34, T. 19 N., R. 6 E.	Cottonwood Coal Co.	100						
255	do	do	Sec. 21, T. 19 N., R. 6 E.	Chas. Lindsey	35	1902	Slightly hard.	Fairly	Pump		Do.
256	do	do	SE. ¼ SE. ¼ sec. 2, T. 19 N., R. 7 E.	J. F. McGraw	20					Alluvium.	
257	do	do	NE. ¼ sec. 33, T. 18 N., R. 6 E.	O. A. Lucas	8						
258	do	do	NE. ¼ sec. 28, T. 18 N., R. 6 E.	Hans Johnson	4						
259	do	do	SE. ¼ sec. 20, T. 18 N., R. 6 E.	F. Nelson	217				Gasoline engine		
260	do	do	SE. ¼ sec. 25, T. 18 N., R. 6 E.	N. Newmeyer	10						
261	do	do	Sec. 36, T. 18 N., R. 6 E.	G. Siegling	22		Soft				Do.
262	do	do	NE. ¼ sec. 15, T. 18 N., R. 6 E.	J. R. Bowen							
263	do	do	NE. ¼ sec. 14, T. 18 N., R. 6 E.	Dan Gist	23		Hard				Stock.
264	do	do	SW. ¼ sec. 14, T. 18 N., R. 6 E.	F. Polcrnik	80	1904	Good	Yes	Windmill		Domestic and stock.
265	do	do	Sec. 5, T. 18 N., R. 7 E.	S. D. Winston	55					Sandstone	
266	do	do	NE. ¼ sec. 5, T. 18 N., R. 7 E.	J. T. Bough	17		Good	No		Shale	

267	do	do	Sec. 11, T. 18 N., R. 7 E	F. Armstrong	13			No.				
268	do	do	Sec. 11, T. 18 N., R. 7 E	W. R. Cresop	22		Good	Yes				
269	do	do	Sec. 29, T. 18 N., R. 8 E	F. J. Ober	16							Domestic.
270	do	do	Sec. 20, T. 18 N., R. 8 E	J. W. Watkins	20	1904	Good	Yes	Pump	Sandstone		Domestic, stock, and garden.
271	do	do	Sec. 28, T. 18 N., R. 8 E	Rob. Williamson	14		Alkaline	No.	Bucket			Stock.
272	do	do	SW. ¼ sec. 1, T. 17 N., R. 6 E	W. Albright	10					Alluvium		
273	do	do	do	G. W. Goodwin	21							Domestic.
274	do	Geyser	SW. ¼ sec. 10, T. 18 N., R. 8 E	W. McGinnis	40	1900						
275	do	do	NE. ¼ sec. 13, T. 18 N., R. 8 E	J. Camerson	7							
276	do	do	NE. ¼ sec. 24, T. 18 N., R. 8 E	H. Koskey	10		Soft	Yes		Shale		
277	do	do	NE. ¼ SE. ¼ sec. 14, T. 18 N., R. 9 E.	W. Kernaghan	23		do	Yes		Clay		
278	do	do	SW. ¼ SW. ¼ sec. 12, T. 18 N., R. 9 E.	J. Todd	9		do	Yes				
279	do	do	NW. ¼ sec. 14, T. 18 N., R. 9 E	R. O'Connor	15		do	Yes				
280	do	do	S. ½ sec. 2, T. 18 N., R. 9 E	F. McCliste	15			Yes				
281	do	do	SW. ¼ sec. 20, T. 18 N., R. 9 E	D. Rankin	14	1900	Soft	Yes	Pump			Domestic and garden.
282	do	do	NE. ¼ sec. 35, T. 18 N., R. 9 E	Gabriel Takola	5	1905	do	Yes	Bucket			Domestic.
283	do	do	NW. ¼ sec. 32, T. 18 N., R. 10 E	J. B. Long	15			Yes	Pump			Do.
284	do	do	do	do	15			Yes	do			Do.
285	do	do	SE. ¼ sec. 32, T. 18 N., R. 10 E	do	15			Yes	do			Do.
286	do	do	NE. ¼ sec. 3, T. 17 N., R. 8 E	—— Larson		1881	Soft	Yes				Domestic, stock, and garden.
287	do	do	NE. ¼ sec. 2, T. 17 N., R. 9 E	H. Haulfa	8		do	No.				
288	do	do	NE. ¼ sec. 29, T. 17 N., R. 9 E	W. Nollar	25							Domestic and stock.
289	do	do	NW. ¼ sec. 10, T. 17 N., R. 9 E	H. P. Schumacher	23							Domestic.
290	do	do	SW. ¼ sec. 5, T. 16 N., R. 9 E	Delphas Leblanc	14		Hard			Limestone		
291	do	do	SE. ¼ sec. 26, T. 16 N., R. 9 E	—— Peterson	8		Poor		Bucket			Stock.
292	do	do	SW. ¼ sec. 19, T. 16 N., R. 10 E	P. O'Harra	8							Domestic and stock.
293	Fergus	Stanford	SE. ¼ SE. ¼ sec. 33, T. 17 N., R. 11 E.	Bower Bros	30	1890		Yes				Do.
294	do	do	NW. ¼ sec. 27, T. 17 N., R. 12 E	do	15			No	Pump			Stock.
295	do	do	NW. ¼ sec. 22, T. 17 N., R. 12 E	do	20			Yes	do			Do.
296	do	do	SW. ¼ NW. ¼ sec. 11, T. 17 N., R. 12 E.	T. Bain	20		Soft		do			
297	do	do	Sec. 27, T. 17 N., R. 12 E	Bower Bros								Do.
298	do	do	SW. ¼ NW. ¼ sec. 27, T. 17 N., R. 12 E.	do					Pump			Do.
299	do	do	NW. ¼ sec. 11, T. 17 N., R. 12 E	do	15				do			Do.
300	do	do	NE. ¼ NE. ¼ sec. 3, T. 17 N., R. 12 E.	do	15				Windmill			Do.
301	do	do	SW. ¼ SW. ¼ sec. 13, T. 16 N., R. 11 E.	P. Westfall	12		Hard	Yes		Drift		
302	do	do	NW. ¼ NW. ¼ sec. 13, T. 16 N., R. 11 E.	J. Skelton	10		Soft	No.				
303	do	do	NE. ¼ sec. 13, T. 16 N., R. 11 E	E. F. Tuttle	12		Hard					
304	do	do	Sec. 24, T. 16 N., R. 11 E	W. Skelton	15		do	Yes				
305	do	do	SW. ¼ sec. 25, T. 16 N., R. 11 E	G. H. Ketchner	18		do					
306	do	do	Sec. 35, T. 16 N., R. 11 E	Fisher ranch	12		Soft	No.				
307	do	do	NE. ¼ sec. 24, T. 16 N., R. 11 E	W. Skelton	15	1900			Pump			Do.
308	do	do	Sec. 31, T. 16 N., R. 12 E	S. S. Hobson	12		Hard					

Partial list of wells of Great Falls region, Montana—Continued.

No.	County.	Locality.	Township, etc.	Owner.	Depth (feet).	Date completed.	Quality of water.	Is supply continuous?	How obtained at surface.	Geologic formation.	Use.
309	Fergus	Stanford	NW. ¼ NW. ¼ sec. 23, T. 15 N., R. 12 E.	Sage Sheep Creek Co.				Yes			Irrigation.
310	do	do	NE. ¼ NW. ¼ sec. 4, T. 15 N., R. 12 E.	J. Segla	9		Good	Yes		Sandstone	
311	do	do	Sec. 4, T. 15 N., R. 12 E.	do	20		do	Yes		do	
312	do	do	do	A. T. Kach	25		do	Yes		Shale	
313	do	do	SE. ¼ SW. ¼ sec. 18, T. 15 N., R. 12 E.	W. J. Hughes	18			Yes		Sandstone	

Artesian wells in the Great Falls region, Montana.

No.	County.	Locality.	Township, etc.	Owner.	Depth.	Diameter.	Date drilled.	Estimated flow per minute.	Quality of water.	Use.	Remarks.
					Ft.	*Ins.*		*Gals.*			
1	Teton	Farmington	SW. ¼ sec. 35, T. 26 N., R. 4 W.	Francois Truchot	47	2	1904	¼	Good	Not used	
2	do	do	SW. ¼ sec. 2, T. 25 N., R. 4 W.	do	50	2	1900	1	do	Stock	
3	do	do	NE. ¼ sec. 11, T. 25 N., R. 4 W.	do	50	2	1900	1	do	do	
4	do	do	SE. ¼ sec. 23, T. 26 N., R. 4 W.	do	100	2		1	do	do	
5	do	do	NW. ¼ sec. 35, T. 26 N., R. 4 W.	H. Weiske	45	2			do	Domestic and stock.	Barely rises above surface.
6	do	do	NW. ¼ sec. 2, T. 25 N., R. 4 W.	G. A. Gorum	45	2	1903	¼	do	Stock	
7	do	do	SE. ¼ sec. 21, T. 26 N., R. 4 W.	B. P. Dirkson	45	2	1902	1		do	
8	do	do	SE. ¼ sec. 15, T. 26 N., R. 4 W.	J. P. Schmidt	75	2		1¼		do	
9	do	do	SE. ¼ sec. 11, T. 25 N., R. 4 W.	John Jackson	37½	2	1903	½		Domestic and stock.	
10	do	do	do	do	34½	2	1905	1½		Irrigation	
11	do	do	SW. ¼ sec. 11, T. 25 N., R. 4 W.	do	29	3¼	1906	1½		do	
12	do	do	do	do	35	3¼	1906				Closed.
13	do	do	NE. ¼ NW. ¼ sec. 6, T. 25 N., R. 4 W.	Peter Egraud	87	5¼	1899	2		Domestic, stock, irrigation.	
14	do	do	Sec. 6, T. 25 N., R. 4 W.	do	87	5				Stock	
15	do	do	do	do	91	8		1		Domestic, stock, irrigation.	

16	do	do	do	do	83	8						Do.
17	do	do	SE. ¼ sec. 3, T. 25 N., R. 4 W.	Elias Rekdehl	31	3½	1905	2½		Irrigation		
18	do	do	do	do	31	3½	1905	1		do		
19	do	do	Sec. 3, T. 25 N., R. 4 W	do	31	3½	1905	3		do		
20	do	do	do	do	16	6		3		do		
21	do	do	do	do	16	2		1½		do		
22	do	do	do	do	16	6	1900	½		Not used		
23	do	do	do	do	42	2	1900	1½		Domestic and stock.		
24	do	do	do	do	16	2	1900	½		Not used		
25	do	do	do	do	36							Not cased, and caved in.
26	Fergus	Stanford	Sec. 4, T. 15 N., R. 12 E.	B. E. Stacks	321				Mineralized	Domestic, stock, and irrigation.		
27	do	do	Sec. 23, T. 15 N., R. 12 E.	Sage Creek Sheep Co.	850	2				Irrigation		
28	do	do	SW. ¼ NE. ¼, sec. 14, T. 15 N., R. 12 E.	Sage Creek Sheep Co's. home ranch.	850	2			Good	Domestic and irrigation.		
29	do	do	NW. ¼ SE. ¼, sec. 21, T. 15 N., R. 12 E.	Razor well	400	2			do			Well not flowing at present.
30	do	do	NE. ¼ NE. ¼, sec. 18, T. 15 N., R. 12 E.	McComb well	400	2			do			Well plugged; not flowing at present.
31	do	do	NW. ¼ NE. ¼, sec. 2, T. 14 N., R. 12 E.	Upper Sage Creek well.	700	2			do			
32	do	do	SW. ¼ SW. ¼, sec. 20, T. 13 N., R. 12 E.	Dry Coulee well	900	2			Mineralized	Stock		
33	Cascade	Belt	NE. ¼ SE. ¼ sec. 32, T. 19 N., R. 6 E.	E. Turner	95				do	Domestic and stock.		
34	do	Great Falls	NE. ¼ sec. 5, T. 20., N., R. 3 E.	J. F. Bryant	160			8	Contains iron.			
35	do	do	NW. ¼ sec. 9, T. 20., N., R. 3 E.	Mat Venetz	180			(a)	do	Irrigation		

a 300 barrels in 24 hours.

ARTESIAN CONDITIONS.

Throughout the eastern part of the area examined, especially that lying east of Belt Creek, the geologic conditions are in general favorable for the occurrence of artesian water. The rocks consist of medium to coarse grained massive sandstone and sandy shale overlain by impervious shale and clay. They dip gradually to the northeast away from the mountains, so that the streams passing over the upturned ends of this porous sandstone and shale lose much of their water. This water in passing underground is soon carried beneath impervious shale farther down on the plains, where it is available as artesian water when the overlying shale is penetrated by deep-well borings. These conditions obtain throughout a zone of varying width along Sage, Willow, Skull, Running Wolf, Surprise, and Arrow Creek valleys.

Throughout the area lying between Belt Creek and Smith River the general geologic and structural conditions are not favorable for the occurrence of artesian water. There is, however, a shallow flowing well of local origin in Box Elder Creek which probably derives its water from the valley filling. In this general vicinity the sandstone members of the Kootenai and the base of the Colorado formation, which are the principal artesian water-bearing beds to the east, occupy summits of more or less detached plateaus, which rise to the south toward the highland lying between the Big Belt and Little Belt mountains. As these sandstone members, which in other localities are artesian water-bearing, occupy only the summits of the higher table-lands far above the mountain streams draining the area, the only water which they can receive is that derived from rainfall. A portion of this is disposed of by run-off and evaporation, while the remainder is free to escape in the numerous marginal springs which occur along the edge of the above-described plateaus; hence the region is one where artesian water is not to be expected.

From Smith River westward along the base of the adjacent mountain ranges the geologic and structural conditions, although different from those above described, are equally unfavorable for the occurrence of artesian water in the adjoining plains region. Along the northern base of Big Belt Mountains the sedimentary rocks, which are of upper Cretaceous age, are cut by igneous rocks over extensive areas, thus preventing them from extending into the higher mountain regions where they might be free to absorb water. The same is true along the base of the Lewis Range bordering this area on the west. Cretaceous rocks, instead of dipping normally away from the uplift, owing to the overthrust fault above described dip toward the mountains, passing under the older Algonkian rocks, which form the higher portion of the range. In the region lying west of Great Falls the water-bearing sandstones of the Kootenai and the base of the

Colorado formation are not exposed, but are covered by several hundred feet of upper Cretaceous sediment, consisting mainly of impervious shale with sandstone members in the upper part. Under these conditions it is apparent that rocks which are water-bearing on the east are on the west, along the base of the Lewis Mountains, completely sealed off from a surface water supply by a great thickness of overlying impervious shale of upper Cretaceous age. The sandstone beds in the upper part of the upper Cretaceous formation also dip toward the mountains in a direction opposite to the flow of the streams which pass over them. Under the above conditions it is obvious that all the water derived from the melting snow of the Lewis Range must either be carried along the valleys of these various streams as a surface flow or an underflow, or be absorbed by the local glacial deposits which cover the formations along the base of the Lewis Range.

From the above it is apparent that the structural relations of the geologic formations in the plains region bordering the Lewis Mountains, including Sun and Teton river valleys, are unfavorable for the occurrence of deep-seated artesian water. Small areas with artesian water of local origin are, however, scattered through this district. Along Muddy Creek, a tributary of Teton River, there is a small district, comprising about 20 square miles, in which a number of successful artesian wells have been obtained. The depth of these wells varies from 16 to 100 feet. The water is relatively pure and is used for both domestic and irrigation purposes. It is obtained from a coarse gravel bed, which is overlain by glacial clay of variable thickness. This artesian area is believed to be supplied with water from the stream in Ralston Gap and upper Muddy Creek. These streams contain numerous swamps in their upper courses, but the water in passing downstream sinks to an underflow a few miles above the artesian area, where it apparently passes under the impervious glacial clay and becomes available as artesian water when this impervious overlying clay is penetrated by well borings. In the lower part of Sun River valley, between Sun River and Great Falls, there are a few shallow wells. The flow of these wells is due to local artesian conditions, which extend over only small areas. The water is obtained in each case from gravel lying in the lower part of the valley filling. This gravel is locally covered by impervious clay, thus producing artesian conditions.

WATER SUPPLY BY DISTRICTS.

GEYSER DISTRICT.

Throughout the area lying to the east of Otter Creek divide the underground water supply is derived mainly from springs, which occur at varying intervals along nearly all of the mountain streams. These springs are more or less numerous in the region adjacent to

the inclosing mountain ranges, as is shown by the water-resource map (Pl. VII), but farther out on the plains they are fewer in number. Shallow wells occur here and there along the stream valleys. They vary in depth from 15 to 25 feet and afford an ample supply of good water, but owing to the large number of springs only a few wells have been sunk. Throughout this district the prospects for artesian water along Lonetree, Arrow, Surprise, Running Wolf, Skull, and Sage Creek valleys are very favorable. The region, as previously stated, is underlain by beds of porous sandstone belonging to the Kootenai formation, which in their outcrop area bordering the Little Belt Mountains absorb more or less water from mountain streams. In their extension northeastward these sandstone beds pass under impervious Colorado shale producing ideal artesian conditions. The Kootenai rocks underlying this region contain a bed of workable coal which has been prospected extensively and is mined at present at several localities. In 1901 the Sand Coulee Mining Company made extensive diamond-drill borings in search of coal along Sage Creek valley. Five holes were bored, ranging in depth from 400 to 700 feet, three in Sage Creek valley in T. 15 N., R. 12 E., one in a small tributary of Willow Creek near Hughes's ranch, and one about 3 miles east of Sage Creek Sheep Company's home ranch. A flow of good water was reported from each of these borings; the largest flow, however, was secured at Sage Creek Sheep Company's home ranch. The water from this well is stored in a small reservoir and used for irrigation purposes. According to the best information which could be obtained concerning these borings, the water in each case was derived from a gray sandstone, probably constituting one of the basal members of the Kootenai formation. The occurrence of these artesian wells in upper Sage Creek valley has a very important significance, for it demonstrates that artesian water can be secured at moderate depths throughout the upper courses of several small mountain-stream valleys in the immediate vicinity, an area comprising a considerable acreage of rich agricultural land. The prospects for artesian water are equally favorable in the upper part of the Skull Creek valley for a short distance northeast of Skull Butte, and it is possible that small flows might be obtained throughout the wide valley of Running Wolf Creek in the vicinity of Stanford. While no practical tests have been made of the artesian water capacity of the Kootenai sandstone underlying Lonetree Creek valley in the vicinity of Geyser, the geologic conditions in this district are favorable for flowing wells. The porous sandstone of the Kootenai formation dips gradually northeastward away from the Little Belt Mountains, passing under the impervious Benton shale, which in the vicinity of Geyser and along Lonetree Creek valley could be penetrated by relatively shallow borings.

MAP OF
GREAT FALLS REGION
MONTANA
SHOWING
IRRIGATION AND AGRICULTURAL AND WATER RESOURCES
LEGEND
INDEX MAP
TETON RIDGE
FORT BENTON BENCH
FREEMOUT BENCH
BURTON BENCH
TETON BUTTES
BOUNDARY LINE
GREAT FALLS
ULM BENCH
HIGHWOOD MTS
LITTLE BELT MOUNTAINS
Stockett
Belt Butte
Fort Shaw Butte
Crown Butte
Wolf Butte
Sun River
Teton River
Missouri River
Great Northern R.R.
Northern Pacific R.R.
Chicago, Milwaukee, St. Paul & Pacific R.R.
Lewis and Clark Co.
Cascade Co.
Chouteau Co.
Fergus Co.
Meagher Co.
Yellowstone Co.
Silver Bow Co.
Deer Lodge Co.
Granite Co.
Ravalli Co.
Flathead Co.
Lake Co.
Sanders Co.
Mineral Co.
Missoula Co.
Powell Co.
Lewis and Clark Co.
Teton Co.
Pondera Co.
Glacier Co.
Toole Co.
Liberty Co.
Hill Co.
Blaine Co.
Phillips Co.
Valley Co.
Roosevelt Co.
Sheridan Co.
Daniels Co.
Richland Co.
Dawson Co.
Wibaux Co.
Prairie Co.
Custer Co.
Fallon Co.
Carter Co.
Musselshell Co.
Golden Valley Co.
Yellowstone Co.
Stillwater Co.
Sweet Grass Co.
Park Co.
Gallatin Co.
Madison Co.
Beaverhead Co.
Jefferson Co.
Broadwater Co.
Meagher Co.
Cascade Co.
Lewis and Clark Co.
Pondera Co.
Teton Co.
Chouteau Co.
Fergus Co.
Petroleum Co.
Judith Basin Co.
Wheatland Co.
Golden Valley Co.
Musselshell

OTTER CREEK DISTRICT.

The Otter Creek district is arbitrarily taken to include the area between Otter Creek divide and Belt Creek. It has an abundant water supply, which is derived largely from springs. A few shallow wells are found along Belt Creek valley and its tributaries, especially in the vicinity of Belt. Shallow wells are also not infrequent on the higher slopes bordering the Highwood and Little Belt mountains. Along Otter Creek numerous springs from the Kootenai sandstone occurring at frequent intervals either in the bottom of the valleys or on the sides of the bluffs furnish an ample amount of good water and make it generally unnecessary to sink wells. The tributaries of Otter Creek from the south, which drain the high plateaus, are also well supplied with spring water from the same source. North of Otter Creek, especially on the higher slopes bordering the Highwood Mountains, there is a strong underflow in the bottom of all the coulees, which is derived from melting snow higher on the mountain slopes. The water thus absorbed in the heads of the coulees high on the slopes appears at the surface lower down in their course in the form of small springs, or it can be easily reached by shallow wells.

GREAT FALLS DISTRICT.

Under the Great Falls district is described the territory lying south of Missouri River between Belt Creek and Smith River. As stated above it is essentially a plateau region more or less dissected by canyons. Throughout the lower part of the district, on the plains east of Great Falls, water for domestic purposes is apparently difficult to obtain, excepting along Box Elder Creek valley, where a number of shallow wells furnish a large amount. Several wells have been dug by the Great Falls Meat Company immediately east of Great Falls. The depths of these vary from 150 to 300 feet, and in no instance has the quality and quantity of the water been entirely satisfactory. Farther to the south and east springs are the chief source of water supply, although a few wells have been sunk. As a rule wells in this portion of the district are not successful, and it is believed that the most satisfactory source of domestic water supply is to be found in the development of the small springs which are more or less abundant. At Stockett and Sand Coulee a few wells have been bored, which are described on page 70, and on the high plateaus southeast of these towns deep borings have been made, which usually failed to secure a satisfactory amount of water. In the vicinity of Stockett there is a local doming of the formations, which exposes the Madison limestone for a considerable distance along Sand Coulee and in Cottonwood and Straight coulees. Wells sunk in this limestone fail to find water, for the upper part of the formation is not water bearing. The Jurassic and Cretaceous formations overlying the Carboniferous limestone

in this vicinity are relatively thin, but they thicken to both the east and the west. Wells bored on the plateaus penetrate the water-bearing sandstone of the Kootenai formation within a distance of 200 to 300 feet from the surface. This sandstone in the vicinity of Stockett and Sand Coulee is not heavily saturated with water, notwithstanding that it is the source of many small springs. The scarcity of water is probably due to the fact, as previously described, that in its southern extension the sandstone caps the higher hills, where the only water which it can absorb is from rainfall and melting snow. In sinking a well in this general region whenever the limestone is reached the boring should be discontinued, for it indicates that all the water-bearing rocks of the region have been penetrated. Along the west side of the district, where the plateaus are capped by the basal sandstone of the Colorado, springs are abundant along the side of the plateaus (see Pl. V, A), and in the valleys good water is obtained from shallow wells. Representative wells and springs in the Great Falls district are listed on pages 43–44 and 53–55.

MISSOURI RIVER VALLEY DISTRICT.

Along Missouri River valley from the base of Big Belt Mountains to a point about 2 miles above Riverdale there is a wide, open valley on the east side of the river in which an abundance of good water is obtained from wells at depths varying from 15 to 25 feet, depending on the distance from the river. A few wells in this valley have been sunk to greater depths in order to obtain a larger supply of water, but generally they have not been successful. Several unsuccessful attempts have also been made to secure artesian water in the valley. This is not practicable, owing to the adverse structural relations described on page 27. The water of shallow wells is derived from alluvial sands and gravel, which have a variable thickness. To the east, on the summit of the high plateau bordering Smith River on the west, water is secured from wells at a considerably greater depth. Here the principal water-bearing horizon is the basal sandstone of the Colorado formation. Wells along this plateau vary from 50 to 150 feet, and a sufficient quantity of water is usually obtained. The extent of the basal Colorado sandstone in this region is shown on the geologic map (Pl. I).

ULM BENCH.

Throughout Ulm Bench, which lies southwest of Great Falls between Missouri and Sun rivers, dry farming is extensively practiced, and the district has been divided into a number of small farms. On these farms wells have been bored which invariably obtain good water at depths rarely exceeding 100 feet. The water is derived from the lower part of the basal Colorado sandstone which caps Ulm Bench. Along the western margin of Ulm Bench, where the over-

lying Colorado shale occupies the surface, the well water is generally more or less mineralized and unfit for domestic purposes.

AREA SOUTH OF SUN RIVER.

West of Ulm Bench throughout the district lying south of Sun River the prospects for underground water are not favorable. The formation occupying the surface in this region is the Colorado shale, which rarely if ever contains pure water. The principal drainage of the area is Little Muddy Creek, a large intermittent stream draining a considerable district south of Square and Fort Shaw buttes. From several field analyses which have been made of water from wells in this valley it has been found to contain an unusually large amount of magnesium and other harmful salts. The well water in this region is so highly mineralized that it is rendered unfit even for stock purposes. The Eagle sandstone, which with the overlying igneous rock caps the prominent buttes in this region, is the only near source of potable water supply.

West of Crown Butte throughout the lower part of the territory drained by Sims Creek prospects for underground water are more favorable. Here the Eagle sandstone underlies the surface, and, while no practical tests have been made, it is believed that wells sunk in this sandstone will probably secure good water.

SUN RIVER VALLEY.

Along the valley of Sun River water for domestic and stock purposes is derived from wells and springs or taken directly from the river. In the lower part of the valley between Sun River and Great Falls many shallow wells have been sunk which furnish a good supply. These derive their waters mainly from the valley wash. Farther up Sun River valley throughout the lower land water is obtained from shallow wells, but back from the streams the depth increases. At Fort Shaw a well was recently drilled and good water found at a depth of 101 feet. This, however, was at the mouth of a small coulee entering Sun River from the south, and it is possible the well did not penetrate the valley filling. In the vicinity of Augusta water is secured from wells at depths varying from 10 to 15 feet, but here the greater part of the domestic water supply is taken directly from Sun River, where, owing to the nearness to Lewis Mountains, it is relatively pure. The prospects for water from deep wells in Sun River valley are very poor, especially in the lower part. Between Manchester and Sims well borings extending through the valley filling will enter the nonwater-bearing Colorado shale, which has a thickness increasing from zero at Manchester to over 800 feet at Sims. Between Sims and Augusta wells sunk below the bottom of the valley

filling would enter the lower part of the Montana, which consists of sandstone and shale in alternating succession. The basal sandstone, comprising the Eagle formation, probably contains water, but the shale overlying the sandstone is believed not to be water bearing.

HIGHLANDS NORTH OF SUN RIVER.

Throughout the high plateau region between Sun and Teton rivers the prospects for underground water are not generally favorable. On that portion of the region lying west of Freezeout Lake no wells, so far as could be ascertained, have been bored which would test the water capacity of the extensive gravel terraces capping the highland, but it is evident from the numerous springs along their eastern margin that they contain more or less water. Underneath the gravel of this district occur the Eagle and Claggett sandstones, which are also water bearing, so that it is believed little difficulty would be encountered in securing a good supply of water from wells in this part of the field. On Freezeout Bench, however, a number of shallow wells have been sunk, which, with one exception, do not furnish a satisfactory amount of water. At Zimmerman's ranch a well 30 feet deep supplies only a small amount of alkali water, while 3 miles to the southwest, at Kruck's ranch, a good well of potable water was secured at about the same depth. Freezeout Bench is composed geologically of a thin veneer of gravel lying on the nonwater-bearing Colorado shale, consequently the only water which can be expected from wells on this bench is at the base of this gravel, which has a thickness varying from 25 to 40 feet. The amount of water available at the base of the gravel will probably not be large, although this may vary locally, and in many cases it is apt to be hard, as the gravel carries considerable lime as a cementing material. Wells penetrating the gravel and entering the Colorado shale would probably obtain alkali water, as this shale rarely furnishes good water. North of Freezeout Bench in some of the coulees tributary to Muddy Creek of Sun River there are small springs fed by the gravel terraces, and here and there a successful shallow well.

FORT BENTON BENCH.

East of the Montana and Great Northern Railway, between Great Falls and Collins, is an area of featureless plains comprising several townships and locally known as Fort Benton Bench, in which the prospects for underground water are very poor. Although this area was not examined in detail, it is known that over a great part of the district the surface formation is Colorado shale. The results of the Banatyne boring, 6 miles east of Dutton, demonstrate that the surface formation and the formations underlying to a depth of at least 1,500 feet are not water bearing. Along Teton Valley, which crosses the

northern part of the district, shallow wells can probably be obtained from the valley wash, although no detailed examination was made of this portion of the field, and it is believed that shallow wells furnishing a moderate supply of water could be secured in some of the small coulees draining northwestward into Teton River.

TETON RIVER VALLEY.

From the west margin of T. 25 N., R. 6 W., eastward as far as the investigation was carried, and especially to the mouth of Deep Creek, there is a strong underflow in Teton Valley. Wells at Chouteau obtain water at three distinct horizons, the first at 7 feet, the second at 27 feet, and the third at 48 feet beneath the surface. There is no marked dissimilarity in the chemical character of the water found at these depths, and in many respects it resembles the water of Teton River. Springs occur in abundance in Teton Valley above Chouteau.

Deep Creek Valley, a tributary of the Teton from the south, has a strong underflow, and an abundance of water is found at depths of 10 to 20 feet below the surface. At the head of Deep Creek are numerous small swamps and glacial lakes, which add materially to both the surface flow and the underflow of Deep Creek valley. North of Deep Creek there is a wide gravel-capped terrace extending toward the mountains, throughout which water could probably be secured from wells not exceeding 30 feet in depth, the water occurring at the base of the gravel. North of this broad terrace there is a badlands district surrounding Teton Buttes, in which there is a scarcity of water.

BURTON BENCH.

Springs are not abundant in the vicinity of Chouteau outside of Teton River valley, and water for domestic purposes is sometimes difficult to obtain. An exception is found in Burton Bench, an area comprising about four townships, which lies north of Chouteau. Bench gravel, loosely cemented, caps this area, thinning gradually from a depth of 30 feet on the southwest to a mere sprinkling on the northeast. Immediately beneath this cap is impervious shale, causing the gravel to act as a reservoir for surface water. Before irrigation ditches had crossed Burton Bench water was obtained at a depth corresponding to the thickness of the gravel, but the water plane has been gradually rising under the influence of irrigation until now an abundant supply is found at 10 to 12 feet beneath the surface. Outside the gravel-capped area water for stock and domestic purposes is taken directly from the ditches, although it contains a considerable quantity of undesirable mineral matter. The average well has a depth of about

60 feet, but is often too strongly impregnated with alkali to be potable. A limited artesian basin of about 20 square miles occurs in the northeastern part of Burton Bench. It is described in detail in the next section.

MUDDY CREEK ARTESIAN BASIN.[a]

General description.—Within an area extending about 6 miles west from where the terminal moraine of the Keewatin ice sheet crosses Muddy Creek valley in T. 25 N., R. 3 W., and having a width of about 3 miles, artesian water is obtained from coarse granitic gravel, overlain by impervious lacustrine clay, at moderate depths below the surface. The writer examined twenty-two flowing wells in this district, all of which furnish a good quality of water. Others that formerly flowed have become clogged by caving where the well was not cased.

The water resources of this basin have not as yet been utilized to any great extent, partly because much of the area is used only for grazing and partly because water for irrigating purposes is readily available from the ditches crossing Burton Bench. In many cases the water is allowed to flow from the wells and no use is made of it, but in many instances outside of the ditch system it is utilized for irrigation as well as for stock and domestic purposes. Two wells in sec. 6, T. 25 N., R. 3 W., water 30 acres of alfalfa, and a group of wells in sec. 11, T. 25 N., R. 4 W., irrigate 100 acres of hay land. In general the wells are 2½ or 3 inches in diameter, as it was found by experiment that a pipe of that size yielded the same flow as a larger one. The smaller size is the more advantageous, since wells of that diameter may be drilled by hand where the depth does not exceed 75 or 80 feet. The method of drilling used in this vicinity is simple. A 1-inch iron rod twisted at one end into a spiral of the diameter desired is used as an auger. The stiff clay which must be penetrated is sufficiently adhesive to allow the drill to bring up a clean core several feet in length. The wells vary in depth from 16 to 100 feet, the deeper being as a rule along Muddy Creek. The variation in depth of these wells indicates that this stream is following rather closely its preglacial channel. Although practically all the artesian wells are south of Muddy Creek, it is probable that there is likewise a considerable area north of that stream where flowing wells might be obtained if, as seems probable, the preglacial valley extends laterally in that direction as well as south. The eastern limits of the basin are defined by the moraine, and since the head of the artesian flow is in no case great, the largest reported being 35 feet, it is not probable

[a] The description of artesian conditions in the Muddy Creek artesian basin is by W. R. Calvert.

that a flow can be secured much farther west than the wells located in sec. 15, T. 6 N., R. 4 W., where the pressure is very weak.

Source.—Brief mention has already been made (p. 61) of the probable source of the artesian water of Muddy Creek basin. The geologic structure of the region and the small head of the flowing wells preclude the theory of a distant or high source. That the artesian flows of this area are due to local conditions is evident from a study of the field. Some water may be supplied by Muddy Creek in its course through T. 26 N., R. 6 W., where the water sinks to an underflow, leaving the stream bed dry for a distance of several miles during the greater part of the year. Since apparently the entire flow reappears at the surface near Bynum, and the stream has not there cut through the lacustrine clays, it is not probable that Muddy Creek contributes much of the artesian water to Muddy Creek basin. On the contrary, the evidence indicates that the artesian basin is connected more directly with the Teton through Ralston Gap. To the observer looking southwest through Ralston Gap it seems probable that the depression was once a large stream valley, and since river sand and gravel are found there the conclusion is further strengthened. From the base of the mountains until it reaches the southeast corner of T. 25 N., R. 6 W., Teton River is not intrenched, but flows in a wide gravel-filled valley. Considerable water is absorbed by this gravel, and it is believed that there is an underflow from Teton River through Ralston Gap to Muddy Creek valley. Springs in sec. 16, T. 25 N., R. 6 W., vary in their flow with the flow of Teton River, the rise in the river increasing within a short period of time the flow of the springs. This phenomenon has been observed even during the dry season of the year, hence it is difficult to attribute this increase in the flow of the springs to any other source than the increase of Teton River. A small stream north of Teton River at present flows toward Ralston Gap, but as it reaches the vicinity of the gap it sinks to an underflow and probably soon passes beneath the impervious lacustrine clay into the porous granitic gravel and becomes available as artesian water to the east when the overlying impervious clay is penetrated by well borings.

WATER SUPPLY OF TOWNS AND VILLAGES.

There are comparatively few towns in the Great Falls region. Great Falls, the largest, derives its city water supply from Missouri River about 1 mile above the business center. From the pumping station, which is located in the NW. ¼ sec. 14, T. 20 N., R. 3 E., the water is pumped directly to a standpipe, located on a prominent hill in the eastern part of town, which has a capacity of 560,000 gallons. From this point it is distributed by a system of 6-inch mains to the

different parts of the city. A field assay of the water taken from one of the hydrants in the main part of the city is as follows:

Analysis of a sample of the Great Falls city water.

[Parts per million.]

Source	Missouri River.
Color	0
Iron	0
Total hardness	125
Alkalinity	180
Alkaline carbonates	32
Alkaline-earth carbonates	160
Chlorides	25

Chouteau, the next town in importance within the district and the county seat of Teton County, depends entirely upon shallow wells for its water supply. Here water is obtained from valley filling at three distinct horizons, which, as previously stated, occur at depths below the surface of 7, 27, and 48 feet, respectively. The largest supply is usually found at a depth of 7 feet below the surface, but wells are generally sunk to the lower horizons in order to obtain water less liable to surface contamination. There is no general town system.

The water supply for the town of Sand Coulee is derived from wells which show considerable variation in depth. In the valley wells are considerably over 100 feet deep. The well owned by Louis Dahn, situated in the valley in the northern part of town, is 168 feet deep. On the slope of the hills bordering the valley water has been secured at depths of 25 to 30 feet, but the supply is variable. In the sides of some of the small coulees in the vicinity of this town there are many water seeps, as previously described, which if properly developed might afford a good domestic water supply.

Considerable difficulty has been encountered in obtaining water for the town of Stockett. In the northern part of the town the people depend for water largely on small springs issuing from the base of sandstone in the sides of the coulee. It has been found by experiment that these small seeps in the hillside, when properly developed, often furnish a good steady flow of potable water. Farther up the coulee, in the main part of town, the Cottonwood Coal Company has sunk a well in the bottom of the main coulee to a depth of 50 feet. From the bottom of this well a tunnel 4 feet wide by 5½ feet high has been dug 90 feet to the east and 125 feet to the west, thus obtaining the greater part of the underflow of the coulee in which Stockett is built. During the driest season of the year the well has furnished 65,000 gallons per day, and the average capacity is over 100,000 gallons a day, most of which is used by the

Cottonwood Coal Company. Wells sunk in the sides of the coulees furnish small quantities of water at varying depths.

The present supply of water for both Sand Coulee and Stockett might be materially increased by the proper improvement of the numerous moist places occurring along the sides of many of the coulees. These moist places or seeps are generally indicated by the deeper green color of the vegetation. In many such localities if shallow excavations were made, water in considerable quantity would probably be obtained, which could easily be piped to houses situated in the valley, thus affording an excellent domestic water supply. The practicability of such a source of water has been demonstrated at a few places in the vicinity of Stockett and at many places along Otter Creek, where springs occur under similar conditions. It is believed also that on many of the small farms in the vicinity of Stockett and Sand Coulee a careful examination of the sides of the coulee might result in the location of moist or seepy places where by inexpensive development water could be procured.

CHEMICAL CHARACTER OF WATER.

During the course of the investigation of the water resources of the Great Falls region samples of water were collected from representative wells and springs for the purpose of analysis. These analyses or assays were made in the field in accordance with the method employed by the water resources branch of the United States Geological Survey. This method is fully described in Water-Supply Paper No. 151. Knowledge was also desired concerning the variation, if any existed, in the quality of waters from the several formations represented in the district. Although a complete analysis of the samples was not possible by the methods employed, the chief characteristics and chemical constituents were determined. These include physical properties, color and turbidity, and those depending more directly upon chemical quality, namely, the amount of iron, calcium, alkaline and alkaline-earth carbonates, sulphates, and chlorides present, and the hardness.

The waters throughout the district are remarkably free from turbidity, only one sample possessing more than a trace. In only a few instances was the presence of coloring matter noted, and iron is a rare constituent in the waters examined.

In the region east of Missouri River the great majority of springs issue from the sandstone or sandy shale of the Kootenai formation. In general the calcium and sulphate content of waters from this formation is high owing to the presence of gypsum in the shale. Near the southern border of the eastern portion of the district examined many springs issue from the Quadrant shale, and these are impregnated to a considerable extent with salts of magnesium and many are

charged with hydrogen sulphide, which renders them unpleasant for drinking. In the district where the surface formation is Colorado shale wells and surface springs are likewise apt to contain considerable magnesium and the alkalinity is high.

In the area west of the Missouri and south of Sun River, with the exception of Ulm Bench, water is relatively scarce and is obtained chiefly from the sandy members of the Montana. As above stated, the water of this district, especially in the Colorado shale area, is characterized by an abundance of magnesium salts, and the alkalinity is often so great as to render it unfit to drink. Several samples of wells and springs from this area also indicate the presence of a large amount of chlorides. In Sun River valley water is usually obtained from alluvium and is not so highly mineralized as that in the area to the south. To the north between Sun and Teton rivers but few samples were taken. There are few wells in this region and springs are not abundant. The samples analyzed, however, indicate that the various members of the Montana group afford water containing more or less mineral matter. In the valley of the Teton, where water is obtained from alluvium, the mineral content, while not especially high, is considerable. On Burton Bench the chief water supply is from the gravel capping consisting principally of limestone pebbles. This gravel contains a large amount of soluble salts. The chlorine content is especially high. In spite of the mineralization, however, it is of better quality than that from wells or springs in the region to the east, where the gravel capping is absent and Colorado shale occupies the surface. From the artesian basin in Muddy Creek valley two samples of water were analyzed. These samples show considerable variation. No. 1, from the eastern portion of the basin, is not so highly mineralized as No. 2, obtained farther west, the difference being chiefly in the calcium and sulphate content. The following table shows the results of the analyses of waters from the various parts of the area investigated. The results are expressed in parts per million.

Analyses of waters from Great Falls region, Montana.

[Parts per million.]

No.	County.	Locality.	Township, etc.	Owner.	Source.	Quantity.[a]	Temperature.	Turbidity.	Color.	Iron.	Calcium.	Total hardness as $CaCO_3$.	Total alkalinity as $CaCO_3$.	Alkaline carbonates as Na_2CO_3.	Alkaline-earth carbonates as $CaCO_3$.	Sulphate radicle (SO_4).	Chlorine.
							°F.										
1	Teton	Chouteau	NW. ¼ NE. ¼ sec. 6, T. 25 N., R. 3 W.	P. Eyraud	Artesian well.	Large	51	0	0	0	Mod.	69	249	0	249	181	19
2	do	do	SE. ¼ sec. 15, T. 26 N., R. 4 W.	J. Schmidt	do	Medium		0	0	0	High	55	279	0	279	600+	5
3	do	do	SW. ¼ sec. 5, T. 24 N., R. 4 W.	W. W. Gamble	Well			0	0	0	Mod.	55	458	0	458	459	114
4	do	do			Teton River			0	0	0	High	111	219	0	219	181	5
5	do	do	SW. ¼ SE. ¼ sec. 25, T. 25 N., R. 5 W.	—— Hodgskiss	Well			0	0	0	Mod.	111	199	0	199	159	10
6	do	do	SW. ¼ SE. ¼ sec. 25, T. 24 N., R. 5 W.	do	do			0	0	0	Mod.	222	319	0	319	125	10
7	do	do	SW. ¼ sec. 19, T. 24 N., R. 4 W.	C. E. Moore	do			0	0	0	High	83	438	0	438	431	27
8	do	do	SW. ¼ sec 1, T. 24 N., R. 4 W.	H. R. Thompson	Spring	Small	50	0	0	0	High	55	359	0	359	573	79
9	do	do	SE. ¼ sec. 20, T. 23 N., R. 4 W.	P. Crossen	do	Medium	52	0	0	0	Mod.	111	598	0	598	150	15
10	do	Hepler	SE. ¼ SE. ¼ sec. 35, T. 22 N., R. 3 W.	F. C. Krucks	Well			0	0	0	Mod.	75	319	0	319	327	39
11	Cascade	Augusta	NE. ¼ sec. 2, T. 21 N., R. 5 W.	—— Flowerree	Spring			0	0	0	Mod.	83	279	42	239	191	19
12	do	do	Sec. 1, T. 21 N., R. 4 W.	do	do			0	226	0	Tr.	41	279	0	279	270	14
13	do	Hepler	NW. ¼ sec. 4, T. 20 N., R. 3 W.	Flowerree's ranch	Well			0	0	0	0	41	399	84	319	153	199
14	do	do	SE. ¼ sec. 4, T. 20 N., R. 3 W.		Sun River			0	0	0	Mod.	69	319	0	319	255	10
15	do	do	NE. ¼ sec. 4, T. 20 N., R. 3 W.	—— Flowerree	Spring	Large		0	0	0	Mod.		279	0	279	222	19
16	do	do	NW. ¼ sec. 35, T. 20 N., R. 3 W.	Carl Meickel	do	do	48	0	0	0	Low	69	279	0	279	300	59
17	do	Sun River	SE. ¼ sec. 34, T. 21 N., R 2 W.	On Government land	do	do	50	0	0	0	Mod.	83	199	0	199	156	10
18	do	do	NE. ¼ sec. 13, T. 19 N., R. 2 W.	Toman Bros	Well			0	160	40	Mod.	111	319	0	319	600+	239
19	do	do	SE. ¼ sec. 4, T. 20 N., R. 2 W.		Spring	Large	52	0	0	0	Mod.	111	199	0	199	116	7
20	do	do	NE. ¼ sec. 22, T. 19 N., R. 1 W.	D. Rease	Well			24	0	10	High	69	399	0	399	600+	109
21	do	do	NE. ¼ sec. 34, T. 21 N., R. 1 W.	M. T. Strong	do			0	0	0	High	139	199	0	199	276	7
22	do	do	NW. ¼ sec. 36, T. 21 N., R. 1 W.	J. C. Adams	do			0	0	0	0	7	199	84	79	150	19
23	do	Great Falls	NE. ¼ sec. 7, T. 20 N., R. 3 E.	K. B. McIver	Spring			0	0	0	High	90	259	0	259	237	14
24	do	do	SW. ¼ NE. ¼ sec. 33, T. 21 N., R. 4 E.		Giant Springs.	638 s.-ft.		0	0	0	Mod.	97	339	0	339	300	10
25	do	do			Missouri River			0	0	0		125	179	31	159	153	24
26	do	do	NE. ¼ sec. 26, T. 20 N., R. 4 E.	Great Falls Meat Co.	Well			0	0	0	High					421	13

[a] Springs with a flow sufficiently large to fill a 2-inch pipe are regarded as large, those between three-fourths inch and 2 inches as medium, and those less than three-fourths inch as small.

Analyses of waters from Great Falls region, Montana—Continued.

No.	County.	Locality.	Township, etc.	Owner.	Source.	Quantity.	Temperature.	Turbidity.	Color.	Iron.	Calcium.	Total hardness as $CaCO_3$.	Total alkalinity as $CaCO_3$.	Alkaline carbonates as Na_2CO_3.	Alkaline carbonates, bicarbonates as $CaCO_3$.	Sulphate ion (as SO_4).	Chlorine.
							F.										
27	Cascade	Sand Coulee	Sec. 13, T. 19 N., R. 4 E.	Louis Dahn	Well			0	0	0	Mod.	84	199	84	149	502	20
28	do	Stockett	NW. ¼ sec. 15, T. 18 N., R. 4 E.	Ed. Connelly	Spring			0	0	0	Tr.	75	279	0	279	205	19
29	do	do	SE. ¼ sec. 14, T. 18 N., R. 4 E.	Davale Culberson	do			0	0	0	High	122	279	0	279	267	19
30	Teton	do	NE. ¼ sec. 17, T. 18 N., R. 4 E.	C. Jaeckel	Well			0	0	0	Mod.	111	229	0	229	164	19
31	do	Great Falls	Sec. 11, T. 19 N., R. 5 E.	— Johnston	Spring			0	0	0	Mod.	86	222	0	222	65	19
32	do	do	SW. ¼ sec. 12, T. 19 N., R. 5 E.	D. Johnston	do			0	0	0	Mod.	48	243	0	243	95	20
33	do	do	SE. ¼ NE. ¼ sec. 12, T. 19 N., R. 5 E.	Ray & Friedrick Sheep Co.	Well			0	0	0	Tr.	48	364	129	324	28	19
34	do	Stockett	NE. ¼ sec. 31, T. 18 N., R. 5 E.	J. Miltsch	do			0	0	0	Mod.	122	279	0	279	150	19
35	do	Belt	NE. ¼ sec. 16, T. 17 N., R. 6 E.	P. Johnson	Spring		45	0	0	0	Mod.	41	199	0	199	357	19
36	do	do	NE. ¼ sec. 15, T. 18 N., R. 6 E.	J. R. Bowen	Well			0	0	0	High	97	249	0	249	201	14
37	do	do	SE. ¼ sec. 22, T. 19 N., R. 6 E.	Chas. Lindsey	do			0	19	0	Mod.	115	283		283	95	19
38	do	do	Sec. 21, T. 19 N., R. 6 E.	do	do			Tr.	0	Tr.	Mod.	77	283	42	243	45	14
39	do	do	SW. ¼ SW. ¼ sec. 14, T. 19 N., R. 6 E.	F. Polutnik	do			0	0	0	Mod.	48	229	0	229	202	10
40	do	do	NE. ¼ sec. 15, T. 19 N., R. 6 E.	A. H. McMillan	do			0	0	0	Mod.	77	283	0	283	Tr	14
41	do	do	Sec. 15, T. 19 N., R. 6 E.	Edgar Mann	do			0	24	0	Mod.	48	314	0	314	84	99
42	do	do	do	do	do			0	4	0	Mod.	48	292	0	292	38	159
43	do	do	Sec. 8, T. 19 N., R. 6 E.	G. Erickson	Spring			0	0	0	Mod.	48	405	0	405	62	149
44	do	do	Sec. 5, T. 19 N., R. 6 E.	W. H. Porter	do			0	0	0	Mod.	57	405	0	405	73	29
45	do	do	NW. ¼ sec. 5, T. 19 N., R. 6 E.	do	Well			0	0	0	Low	57	243	0	243	29	10
46	do	do	NW. ¼ sec. 3, T. 19 N., R. 6 E.	Joe Bogner	Spring			0	0	0	Mod.	57	324	0	324	38	16
47	do	do	SE. ¼ NE. ¼ sec. 35, T. 20 N., R. 6 E.	P. P. Buchanon	do			0	47	1	High	67	141	0	141	222	29
48	do	do	SW. ¼ sec. 26, T. 20 N., R. 6 E.	J. B. Long	Well			0	0	0	Tr.	83	279	0	279	112	17
49	do	do	Sec. 33, T. 20 N., R. 7 E.	— Gilette	do			0	47	0	Mod.	48	324	0	324	900	19
50	do	Cora	SW. ¼ SE. ¼ sec. 3, T. 18 N., R. 7 E.	F. Armstrong	do			0	52	0	Mod.	57	191	0	191	100	19
51	do	Belt	SW. ¼ sec. 8, T. 18 N., R. 7 E.	T. D. Joscelyn	Spring			0	0	0	Mod.	57	202	42	162	80	12
52	do	do	NW. ¼ sec. 10, T. 18 N., R. 7 E.	G. W. Blake	do			0	0	0	Low	48	445	21	425	48	14
53	do	do	NW. ¼ sec. 18, T. 18 N., R. 7 E.	Chas. Ashwert	do			0	47	0	Mod.	38	121	0	121	256	10
54	do	do	NW. ¼ sec. 21, T. 18 N., R. 7 E.	T. Armstrong	do			0	19	0	Mod.	57	220			54	10
55	do	do	SE. ¼ SE. ¼ sec. 30, T. 18 N., R. 7 E.	F. J. Ober	do	Medium.		Tr.	0	0	Mod.	67	222	0	222	94	10
																	10
56	do	do	SE. ¼ sec. 25, T. 17 N., R. 7 E.	Bundy & Henderliden	do	Large		0	0	0	Mod.	48	245	0	245	312	
57	do	do	NE. ¼ sec. 4, T. 16 N., R. 8 E.	J. Laboie	Well			0	0	0	Mod.	28	243	0	243	324	10

58	do	do	NE. ¼ sec. 19, T. 17 N., R. 8 E.	Bundy & Henderliden	Spring	Small		0	0	0	Tr.	28	405	0	40	Tr.	5
59	do	Geyser	NE. ¼ sec. 3, T. 17 N., R. 8 E.	—— Larson	do			0	0	0	High	57	283	0	283	384	10
60	do		NW. ¼ SE. ¼ sec. 28, T. 18 N., R. 8 E.	R. Williamson	Well			0	0	0	Mod.	67	139	0	139	96	14
61	do	Belt	NE. ¼ sec. 22, T. 18 N., R. 8 E.	A. A. Dawson	Spring			0	0	0	0	28	40	0	40	0	10
62	do	do	SW. ¼ NW. ¼ sec. 20, T. 18 N., R. 8 E.	J. W. Watkins	Well			0	0	0	Mod.	28	330	0	330	403	14
63	do	do	SW. ¼ sec. 6, T. 18 N., R. 8 E.		do			Tr.	24	0	Low	38	364			102	10
64	do	Geyser	SW. ¼ sec. 3, T. 18 N., R. 8 E.	C. W. McClay	Spring			0	0		High	77	40	0	40	492	10
65	do	do	SE. ¼ SE. ¼ sec. 9, T. 18 N., R. 9 E.	C. J. Ellis	do			0	0	0	High	111	162	0	162	64	10
66	do	do	NE. ¼ sec. 19, T. 17 N., R. 9 E.	G. L. Lee	do			0	0	0	Mod.	83	202	0	202	73	7
67	do	do	NE. ¼ sec. 12, T. 18 N., R. 9 E.	S. C. Philbrick	do			0	0	0	Mod.	83	303	0	303	256	7
68	do	do	SW. ¼ sec. 20, T. 18 N., R. 9 E.	D. Rankin	Well			0	0		High	67	202	0	202	600+	10
69	do	do	SE. ¼ sec. 4, T. 16 N., R. 10 E.	T. Shannon	Spring		46	0	0	0	High	83	202	0	202	384	7
70	do	do	SE. ¼ sec. 19, T. 16 N., R. 10 E.	Pat. O'Hara	do	Large	45	0	0	0	Mod.	111	202	0	202	Tr.	5
71	do	do	SW. ¼ sec. 20, T. 16 N., R. 10 E.	J. H. Skelton	do	do	41	0	0	0	Mod.	83	81	0	81	136	5
72	do	Stanford	NW. ¼ SW. ¼ sec. 13, T. 16 N., R. 10 E.	First National Bank	do	Medium		0	0	0	Mod.	134	364	0	364		5
73	do	do	NE. ¼ NE. ¼ sec. 25, T. 16 N., R. 10 E.	do	do	Small	45	0	0	0	High	27	324	0	324	574	7
74	do	do	SW. ¼ sec. 34, T. 16 N., R. 10 E.	—— Burgess	do	do		0	0	0	Mod.	69	121	0	121	132	5
75	do	do	SE. ¼ NE. ¼ sec. 2, T. 15 N., R. 10 E.	—— Butterfield	do	do		0	43	0	Mod.	69	121	0	121	174	5
76	Fergus	do	NE. ¼ sec. 11, T. 17 N., R. 11 E.	Bower Bros	do	do		0	0	0	High	97	263	263		362	10
77	do	do	SE. ¼ NE. ¼ sec. 33, T. 17 N., R. 11 E.	do	Well			0	0	0	Mod.	38	324	0	324	600+	17
78	do	do	NE. ¼ sec. 24, T. 16 N., R. 11 E.	W. Skelton	Spring			0	0	0	High	83	223	0	223	238	10
79	do	do	SW ¼ sec. 10, T. 15 N., R. 11 E.	Bower Bros	do			0	0	0	Mod.	139	219	10	209	154	5
80	do	do	SE. ¼ sec. 4, T. 15 N., R. 12 E.	B. E. Stacks	Well			0	0	0	High	83	259	0	259	313	7
81	do	do	NW. ¼ NW. ¼ sec. 23, T. 15 N., R. 12 E.	Sage Creek Sheep Co.	do			0	0	0	Mod.	111	159	0	159	313	10

WATER POWER.

DESCRIPTION OF FALLS.

The water power of the Great Falls region is undoubtedly one of its most valuable assets, although at present it is practically undeveloped. Between the Great Northern Railway bridge at Great Falls and the mouth of Belt Creek, a distance of approximately 10 miles, Missouri River has a total fall of 612 feet. Of this amount the greater part occurs at five different places, Black Eagle, Coulters, Rainbow, Crooked, and Big falls, which are collectively known as the Great Falls of Missouri River. (See Pl. III, *A*, *B*, and Pl. IV, *A*, *B*.) The remainder of the fall which takes place between the above-mentioned points is in the form of rapids occurring at varying intervals between the cataracts. Conflicting reports are current regarding the exact height of the different falls. According to the first measurements, which were made by Lewis and Clark in 1804, Black Eagle Falls have a drop of 20 feet, Coulters 14 feet 7 inches, Rainbow 47 feet 8 inches, Crooked 19 feet, and Big Falls 87 feet ¾ inch. In M. S. Parker's description of the falls, published in 1894, the following measurements are given, which are somewhat at variance with those above quoted, although in a previous article by Parker, published in 1892, favorable comment is made on the accuracy of the Lewis and Clark measurement. Parker ascribes to Black Eagle Falls a drop of 20 feet, to Coulters 14 feet, to Rainbow 37 feet, to Crooked 19 feet, and to Big Falls 75 feet 4 inches. No careful measurements of these falls were made by the author while in the field, but according to the best information which can be obtained from local engineers familiar with the region the height of Black Eagle Falls, the first of the series, located at the Boston and Montana smelters, is 41 feet, including the masonry dam, which has been built on their crest. Coulters Falls, which are about 1 mile farther downstream and just above the Great Northern Railway bridge, have a drop of 14 feet. A short distance below the railroad bridge and about one-eighth of a mile from Coulters Falls, are Rainbow Falls, which have a drop of 37 feet. Crooked Falls, so named from their irregular shape, which occur about one-fourth of a mile farther downstream, drop 20 feet, and 4 miles still farther down the Missouri the water at Big Falls plunges over a precipice 75 feet high. Views of Black Eagle, Rainbow, Crooked, and Big falls are shown in Pls. III, *A*, *B*, and IV, *A*, *B*, respectively.

UTILIZATION.

At present power from only Black Eagle Falls has been developed. The Boston and Montana Smelter Company have constructed a large masonry dam which develops sufficient power, supplemented by an

auxiliary steam plant, to supply the large smelters owned by that company on the north side of Missouri River at this place. The amount of horsepower developed at Black Eagle Falls varies from 6,000 to 12,000, depending on the season. In addition to the large power plant located on the north side of the river there is also a smaller power plant on the south side, which is used as an electric station for power for street railways, electric-light plant, Royal Milling Company's flour mills, and a number of smaller factories.

UNDEVELOPED POWER.

Coulters, Rainbow, Crooked, and Big falls are wholly undeveloped, although they are apparently more favorably situated for power development than Black Eagle Falls. The following table shows the available horsepower of the different falls:

Available horsepower of the Great Falls of Missouri River.

Name.	Height.	Discharge.	Horsepower.
	Feet.	*Second-feet.*	
Black Eagle Falls	41	1,800	6,545
Coulters Falls	14	2,400	3,272
Rainbow Falls	37	2,400	8,072
Crooked Falls	20	2,400	4,333
Big Falls	75	2,400	16,363
			38,585

The above statements are based on a minimum flow of Missouri River above Black Eagle Falls of 1,800 second-feet, as shown by Government discharge measurements extending over a period of four years, from 1902 to 1905, inclusive. These measurements were taken at Cascade, where the Geological Survey has maintained a gaging station for a number of years. To the measurements of this gaging station is added an average minimum flow of Sun River, which empties into the Missouri a short distance above Great Falls and between Cascade and Black Eagle Falls. Below Black Eagle Falls Giant Springs add to the flow of the river approximately 600 cubic feet per second, which apparently does not vary at different seasons of the year. Taking this amount into consideration Coulters, Rainbow, Crooked, and Big falls would have a minimum flow of about 2,400 second-feet. This amount has been used for calculating the available horsepower at these cataracts. Of course it should be borne in mind that by the proper development of any one of these falls the amount of available horsepower could be materially increased. It is possible also that by constructing suitable dams the fall of the numerous small rapids which occur between the cataracts could be made to furnish considerable power, but as such questions depend entirely on the nature and extent of the development, no esti-

mate as to the total horsepower which could be developed under ideal conditions of improvement in the vicinity of Great Falls is here given.

IRRIGATION.

GENERAL STATEMENTS.

Irrigation has been practiced along the valleys of the larger streams in the Great Falls region for many years, but its growth and development have been necessarily slow until recently. Prior to the building of railroad lines into the district, which was in 1886, and for some time afterwards, the inhabitants of the region were principally engaged in cattle raising and mining, and only small tracts were irrigated here and there along the valleys. With the growth in population and the increased demand for agricultural produce, irrigation began to be more generally practiced along the larger streams, resulting eventually in the construction of several large canals by private individuals or small companies organized among the ranchmen. Extensive preparations are now being made, both by the Government and by private enterprises, to reclaim larger tracts of land along Sun and Teton rivers and the highland lying between these two streams. (See Pl. VII.)

SUN RIVER VALLEY.

Sun River valley is one of the most extensively irrigated valleys in the Great Falls region. There are a large number of small ditches covering the lower lands along each side of the river from the vicinity of Great Falls to the base of the Lewis Mountains. In addition to these several large canals have been constructed by individual ranchmen and small companies organized among the farmers. The largest of these is the Flowerree Trustee ditch, which is taken out of North Fork of Sun River near the center of sec. 20, T. 21 N., R. 6 W., and extends for about 25 miles eastward, covering a large territory of table-land bordering Sun River on the north. Another and somewhat smaller ditch occurs on the same side of Sun River farther downstream, known as the Sun River canal. Its headgate is located near the east end of old Fort Shaw Reservation, and it furnishes water to an area nearly a mile in width, extending east as far as Muddy Creek of Sun River. One of the largest canals on the south side of Sun River is the Crown Butte canal, constructed by individual enterprise, which leaves the river in the southeast corner of sec. 6, T. 20 N., R. 4 W., and extending eastward crosses Sims Creek in a big loop, and passing through a low divide north of Crown Butte empties into the head of Little Muddy Creek valley. A number of smaller ditches are found along the south side of the river, including, from east to west, Campbell, Eder, and Richling Company, Bickel Burk,

Butler, Clemens, Phyllip, Mayer, and others farther up South Fork of Sun River. The Government irrigation project along the south side of Sun River, known as the Fort Shaw canal, covers about 16,000 acres in the vicinity of the Fort Shaw Reservation. The larger features of irrigation along Sun River valley are shown on the map (Pl. VII).

TETON RIVER VALLEY.

Irrigation is not extensively practiced along the valley of Teton River in the vicinity of Chouteau. A few small farms are irrigated around Chouteau and near the head of Spring Creek, but, with these exceptions, irrigation is confined to Burton Bench, where a number of large canals have been constructed. Burton Bench, which is one of the largest, if not the largest, irrigation district in the area described, is supplied with water by three large canals, the Burton, Cooperative, and Eldorado canals. These canals are all taken from the Teton River 10 miles above Chouteau. Their approximate location and the land irrigated by them is shown on Pl. VII.

The Cascade Land Company's ditch, which is taken out of Deep Creek on the south side about 3 miles above its mouth, extends around the east side of Priest Buttes, crosses by siphon flume the north end of Freezeout Basin, and continues to the Cascade Land Company's home ranch, where it furnishes water for several hundred acres of land situated in the southwestern part of T. 23 N., R. 3 W. A short distance below the headgates of the Cascade Land Company's ditch there is another ditch which is owned by the S. T. Cattle Company. It extends down the river about 6 miles, where it supplies water for over a thousand acres of land in T. 24 N., Rs. 3 and 4 W. The location of the above-described ditches and the approximate limits of the land to which they supply water are shown on Pl. VII.

OTHER VALLEYS.

Along the east side of Missouri River in the vicinity of Cascade, irrigation has been practiced for many years. No large canals have been constructed in this region, but a number of small ditches carry water some distance out from the river to scattered ranches along the valley. In Smith River valley are a number of irrigated ranches, but only a relatively small portion of the valley land is now cultivated. Hound Creek, one of its principal tributaries from the west, has a few small irrigated ranches along its course. Considerable irrigation is carried on all along Belt and Otter Creek valleys. No large canals have been built along these streams, owing mainly to the fact that the valleys are narrow and the amount of irrigable land small. Short ditches which occur at frequent intervals supply

water to small fields. Throughout the eastern portion of the district the streams carry only a small flow of water, all of which has been appropriated for irrigation purposes. In some cases private reservoirs have been constructed to increase the available supply by storing flood waters.

AGRICULTURE.

Throughout the lower Plains portion of the Great Falls region the aridity of the climate renders tillage without irrigation impracticable, but in the plateau region bordering Little Belt and Highwood mountains dry farming is extensively practiced far up the slopes of these ranges. The cultivated portions of the area examined comprise a relatively small part of the entire district, the remainder being utilized for pasturage of cattle—an important industry of the region, to which the upland areas are well adapted. Among the chief agricultural products are wheat, oats, barley, rye, spelt, flax, alfalfa, tame hay, potatoes, and a variety of garden vegetables, most of which are consumed by workers in the mines and smelters surrounding Great Falls. The main crop is wheat, which has a yield varying from 20 to 40 bushels per acre. Both winter and spring wheat is raised, but the preference seems to be for winter wheat at present. Oats have a large yield, ranging from 35 to 45 bushels per acre, and the yield of potatoes and other vegetables is unusually large.

Cascade County, Mont., is one of the most important grain centers in the State. Fruit raising is a growing industry, and many young, well-kept orchards are to be found throughout the district; currants, gooseberries, and strawberries are among the important fruits. The seasons are ordinarily of sufficient length to insure the maturity of all cultivated crops, except on the higher slopes bordering the inclosing mountain ranges, where the time between killing frosts is short.

The distribution and extent of the land irrigated, also the area in which dry farming is practiced, are shown on Pl. VII.

CLIMATE.

TEMPERATURE.

General statements.—The temperature records of this general region present a very wide range between extremes—a feature which is apt to cause an erroneous impression. Though the annual range is probably as large as in any other part of the United States, the periods of low temperature are of short duration and are generally attended by dry, calm atmosphere. Under these conditions the low winter temperatures are not so severe on life in general as much higher temperatures would be under less favorable conditions. Owing to this fact stock can successfully winter on the range without shelter. The summer temperatures, although high, are not so oppressive as an equivalent temperature would be in more humid atmosphere in

low altitudes. The summer days are long and often very hot, but as evening approaches the air cools rapidly by radiation, and the nights are cool and comfortable.

Great Falls region.—Very few meteorological data are available regarding the mountainous districts surrounding the Great Falls region, but there are a number of places lower down on the plains where systematic observations have been carried on for a number of years. The first meteorological station was established at Chouteau in 1890, and in December of the following year a similar station was placed at Great Falls. The observations begun at Chouteau were continued for only one year, but the station was reestablished at this place in January, 1905. Climate data began to be collected in a systematic way at Sun River in March, 1895, and a station was established at Augusta in July, 1896. Records of the temperature have been collected at Cascade, Mont., since May, 1894, but observations during the first two months are not quoted below. At Great Falls, where the most systematic information has been procured, and where the results are in a measure representative of the district, the mean monthly temperatures from 1893 to 1903, inclusive, are as follows:

Mean monthly temperatures for ten years at Great Falls, Mont.

	°F.		°F.
January	26	July	68
February	26	August	67
March	32	September	56
April	45	October	49
May	55	November	33
June	62	December	30

Throughout the above-described period the mean of the maximum temperatures at Great Falls varied from 36° in January to 83° in July. The absolute maximum temperatures range from 60° in December to 106° in August, the mean of the minimum from —14° in January to 54° in July, and the absolute minimum from —38° in January to 35° in July.

Although the climatic observations made at Great Falls may be regarded as in a measure representative of the district, yet for the purpose of comparing the variations between stations located near the base of the mountains and those farther out on the plains, the following comparative table is introduced. The highest temperature ever recorded at the Great Falls station is 106°, which occurred in August, 1892. The minimum temperature recorded was —38° in January, 1893. The average date of the first killing frost in autumn is in the latter part of September, while the average date of the last killing frost in spring is about the first of May. The direction of the prevailing wind is southwest, except in June, when it is west.

Comparative temperatures (°F.) at Augusta, Great Falls, Cascade, and Chouteau for five years (1902–1906, inclusive).

	Maximum.					Minimum.					Mean.				
	1902.	1903.	1904.	1905.	1906.	1902.	1903.	1904.	1905.	1906.	1902.	1903.	1904.	1905.	1906.
January:															
Augusta	58	63	54	55	60	−30	−14	−10	−28	−26	23.9	31.0	27.4	18.2	28.2
Great Falls	60	56	52	47	53	−25	− 2	− 7	−21	−24	27.6	31.8	29.4	18.2	29.2
Cascade	...	...	...	56	...	...	...	...	−21	−28	...	...	...	19.4	...
Chouteau	...	...	...	...	61	...	...	...	...	−21	...	...	...	...	28.5
February:															
Augusta	58	55	54	65	63	−19	−21	−20	−43	−14	26.6	24.0	15.8	18.6	29.2
Great Falls	60	55	52	62	55	−16	−18	−16	−30	−10	27.5	25.9	15.1	20.2	30.1
Cascade	...	...	...	63	60	...	...	...	−38	− 9	...	...	...	22.3	33.0
Chouteau	...	...	...	64	63	...	...	...	−34	−10	...	...	...	19.9	30.0
March:															
Augusta	55	62	58	70	70	−16	−13	−21	− 7	−35	29.2	25.7	22.8	37.0	23.2
Great Falls	56	63	45	71	68	− 6	− 7	−13	9	−24	35.0	27.2	16.6	40.8	26.2
Cascade	...	...	...	75	72	...	...	...	1	−31	...	...	...	42.0	27.2
Chouteau	...	...	...	69	71	...	...	...	6	−28	...	...	...	37.8	24.3
April:															
Augusta	66	72	79	73	86	15	10	16	4	14	39.8	39.5	44.8	41.2	45.6
Great Falls	68	72	72	74	82	20	20	20	19	25	43.7	43.8	48.2	44.6	49.0
Cascade	...	...	...	76	86	...	...	...	14	20	...	...	...	45.5	50.8
Chouteau	...	...	...	72	85	...	...	...	11	22	...	...	...	41.6	47.4
May:															
Augusta	86	84	77	78	85	25	24	20	26	19	50.8	47.2	49.5	46.6	46.6
Great Falls	86	89	82	78	87	30	27	30	31	30	56.2	51.0	54.2	50.6	50.1
Cascade	...	...	...	82	88	...	...	...	28	28	...	...	...	51.3	51.0
Chouteau	...	...	...	81	90	...	...	...	25	22	...	...	...	47.2	48.6
June:															
Augusta	83	86	90	83	82	27	32	32	30	30	55.2	60.0	56.4	53.8	53.0
Great Falls	86	87	94	88	80	34	40	41	35	40	57.4	65.0	62.0	58.0	57.7
Cascade	...	...	...	88	85	...	...	...	33	37	...	...	...	58.4	59.4
Chouteau	...	...	...	84	80	...	...	...	31	35	...	...	...	55.6	55.4
July:															
Augusta	87	93	...	91	88	36	34	...	31	38	59.9	60.0	...	67	63.4
Great Falls	92	92	97	93	92	42	42	48	48	45	65.4	65.6	69.5	68.4	69.8
Cascade	...	...	99	95	98	...	...	41	44	38	...	...	68.6	68.5	71.4
Chouteau	...	...	...	98	94	...	...	...	34	38	...	...	...	65.3	66.4
August:															
Augusta	86	92	91	89	93	35	32	31	31	31	61.1	60.3	60.8	62.9	60.2
Great Falls	89	94	86	93	96	43	42	17	42	44	67.0	65.5	53.6	70.2	65.4
Cascade	...	...	100	96	94	...	...	35	40	38	...	...	67.4	70.2	63.4
Chouteau	...	...	...	95	97	...	...	...	35	39	...	...	...	65.6	62.5
September:															
Augusta	83	80	88	85	...	23	20	19	27	...	49.9	50.6	55.6	55.1	...
Great Falls	83	80	90	86	...	28	30	30	32	...	56.7	56.1	57.8	59.6	...
Cascade	...	...	95	...	...	...	...	26	...	...	...	...	60.4	...	...
Chouteau	...	...	...	87	...	...	...	...	27	...	...	...	...	57.2	...
October:															
Augusta	80	80	81	78	...	19	20	11	− 2	...	45.8	48.8	47.8	40.6	...
Great Falls	77	78	80	77	...	22	25	28	2	...	48.8	51.8	50.6	41.0	...
Cascade	...	...	86	85	...	...	...	22	3	...	...	...	48.4	45.0	...
Chouteau	...	...	...	78	...	...	...	...	− 4	...	...	...	...	40.6	...
November:															
Augusta	54	72	74	74	...	− 2	−39	10	−28	...	28.9	27.0	43.0	35	...
Great Falls	58	70	65	64	...	6	−25	17	−18	...	32.6	31.6	45.8	36.7	...
Cascade	...	...	66	69	...	...	...	13	21	...	...	...	47.6	...	...
Chouteau	...	...	...	75	...	...	...	...	−24	...	...	...	...	37.1	...
December:															
Augusta	52	61	60	56*	...	−17	−14	−26	−10	...	24.2	33.0	29.7	32	...
Great Falls	52	56	54	51	...	10	−12	−20	16	...	23.6	33.8	31.4	31.4	...
Cascade	...	...	67	...	...	...	...	−24	...	...	...	...	33.3	...	...
Chouteau	...	...	...	58	...	...	...	...	− 9	...	...	...	...	33.0	...

RAINFALL.

There is only a moderate amount of rainfall throughout the Great Falls region, especially in that portion bordering the adjacent mountain ranges. On the lower lands farther out on the plains more arid conditions prevail. A characteristic of the annual precipitation in this region, as in other parts of Montana, is that a large percentage falls during the growing season. The amount of rainfall received during the four summer months nearly equals that for the remainder

of the year—a feature peculiarly favorable for agriculture. The mean monthly precipitation at Great Falls for a period of ten years, 1893 to 1903, inclusive, is as follows:

Mean monthly precipitation at Great Falls, Mont.

January	0.6	July	1.6
February	.5	August	.6
March	.7	September	1.1
April	1.2	October	.4
May	2.6	November	.8
June	2.8	December	.5

During the period of ten years above described the total rainfall for the driest year was 6.7 inches, while the total for the wettest year was 17.3 inches. The average depth of snow for this period is 39.6 inches, and the heaviest snowfall in twenty-four hours is 9.3 inches.[a]

In order to show the relative precipitation of the regions adjacent to the mountains and those farther out on the plains, the following comparative table is introduced:

Relative precipitation at Augusta, Great Falls, Cascade, and Chouteau for five years (1902–1906, inclusive).

	Rain and snow (melted).					Snow.				
	1902.	1903.	1904.	1905.	1906.	1902.	1903.	1904.	1905.	1906.
January:										
Augusta	0.14	0.19	0.21	0.40	0.51	3.3	1.5	2.5	4.0	5.0
Great Falls	.16	.08	.17	.32	.32	1.6	.7	1.7	.....	.....
Cascade	.....	.....	.....	.23	.20	.....	.....	.....	4.5	7.1
Chouteau	.....	.....	.....	.....	.12	.....	.....	.....	.....	.....
February:										
Augusta	.49	.18	.15	.40	.45	8.2	2.0	1.0	4.0	4.5
Great Falls	1.02	.35	.51	.17	.77	9.8	3.5	4.9	.....	.....
Cascade	.....	.....	.....	.31	.85	.....	.....	.....	9.0	10.0
Chouteau	.....	.....	.....	.12	.08	.....	.....	.....	2.4	Tr.
March:										
Augusta	.76	1.00	2.18	2.27	.70	14.0	10.0	18.0	1.5	7.0
Great Falls	.19	.89	2.20	.66	73	1.6	8.0	22.0	.....	.....
Cascade	.....	.....	.....	.55	.63	.....	.....	.....	8.5	9.1
Chouteau	.....	.....	.....	.56	.31	.....	.....	.....	4.6	.....
April:										
Augusta	.35	1.71	.50	1.78	.92	.....	13.0	1.5	10.0	.....
Great Falls	.05	2.00	.62	.68	1.17	.....	.....	Tr.	.....	Tr.
Cascade	.....	.....	.....	.84	1.16	.....	.....	.....	11.5	.....
Chouteau	.....	.....	.....	.55	.56	.....	.....	.....	.....	.....
May:										
Augusta	4.16	2.48	.92	1.52	6.43	2.5	8.0	6.0	.....	.....
Great Falls	5.93	1.84	1.16	1.99	5.03	.....	.....	.....	Tr.	.....
Cascade	.....	.....	.....	2.30	5.79	.....	.....	.....	Tr.	.1
Chouteau	.....	.....	.....	1.45	4.47	.....	.....	.....	2.0	.....
June:										
Augusta	.79	1.36	.99	4.97	.97	.....	.....	.....	.....	.....
Great Falls	4.02	2.19	1.06	4.23	5.59	.....	.....	.....	.....	.....
Cascade	.....	.....	.....	5.48	2.69	.....	.....	.....	.....	.....
Chouteau	.....	.....	.....	2.63	1.57	.....	.....	.....	.....	.....
July:										
Augusta	.....	3.54	.....	1.70	1.00	.....	.....	.....	.....	.....
Great Falls	2.14	2.74	.97	.67	.88	.....	.....	.....	.....	.....
Cascade	.....	.....	.29	1.04	.80	.....	.....	.....	.....	.....
Chouteau	.....	.....	.....	1.25	1.14	.....	.....	.....	.....	.....
August:										
Augusta	.77	1.51	.32	1.44	2.18	.....	.....	.....	.....	.....
Great Falls	.55	.74	1.18	.82	2.66	.....	.....	.....	.....	.....
Cascade	.....	.....	.12	2.05	3.15	.....	.....	.....	.....	.....
Chouteau	.....	.....	.....	.70	2.75	.....	.....	.....	.....	.....

[a] A portion of the data above and in the statements immediately following are for the period from 1893 to 1903. The remainder is computed from the establishment of the station in 1891.

Relative precipitation at Augusta, Great Falls, Cascade, etc.—Continued.

	Rain and snow (melted).					Snow.				
	1902.	1903.	1904.	1905.	1906.	1902.	1903.	1904.	1905.	1906.
September:										
Augusta	.36	.75	.16	.07						
Great Falls	.74	.29	.14	.18			Tr.			
Cascade	..	..	13							
Chouteau				.27					..	
October:										
Augusta	Tr.	.27	.10	.47			2.2	1.0	5.0	
Great Falls	.07	.45	.44	26			Tr.	Tr		
Cascade	..	..	.29	.38				Tr.	4.0	
Chouteau	..	..	..	.10						
November:										
Augusta	.32	1.71	Tr.	.60				16.0	Tr	6.0
Great Falls	.45	.83	.01	1.25				8.3		
Cascade	..	..	.02	1.50						10.3
Chouteau	..	..	..	26						
December:										
Augusta	1.06	.69	.40	10			6.0	4.0	1.0	
Great Falls	.39	.91	.54	.18			9.1	8.0	1.8	
Cascade			.38	.20					2.0	
Chouteau		..	.	Tr.					Tr.	

CULTURE.

Settlement here as elsewhere is determined by geologic and climatic conditions. Along all the larger stream valleys where surface water for irrigation purposes is available settlements are numerous, but much of the upland and grazing districts is thinly populated. On the higher slopes bordering the mountains in the zone of increased rainfall many small farms occur, some of which are among the best improved places found in the district.

One relatively large town, three medium-sized coal-mining towns, and a number of smaller trading points are in the district. Great Falls, a town of 18,000 inhabitants and a thriving business center, is located on Missouri River near the north-central portion of the district. Although at present none of its railroad lines are transcontinental, they are the most important connecting lines between the main lines of the Great Northern and the Northern Pacific, and when the Billings and Northern road, now being constructed between Billings and Great Falls, is completed it will open up a new transcontinental route through Great Falls to the northwest coast. At present railroad lines extend in four directions from Great Falls: The Great Northern southwestward to Helena and Butte; the Montana and Great Northern northwestward to Shelby Junction, a point on the main line of the Great Northern; the Great Northern extending northeastward to Havre, another point on the Great Northern main line; and the Neihart branch of the Great Northern connecting Great Falls with Neihart, a silver-mining town in the Little Belt Mountains about 100 miles to the southeast. This road has a short branch line leaving it at Gerber station for Stockett and Sand Coulee, two of the larger coal-mining camps. The Boston and Montana Consolidated Copper and Silver Mining Company's smelters and

refineries are located at Great Falls; also the Royal Milling Company, besides a number of smaller business enterprises. The ore handled at the smelters comes from Butte and Anaconda; this, together with the coal and limestone used in the operation of the plant, makes a relatively large freight traffic for Great Falls, while it also furnishes employment for a large force of men.

Belt, one of the largest coal-mining towns in the region, has a population of about 1,000, composed mainly of employees of the Anaconda Copper Mining Company, the largest operators at this place. It is located on Belt Creek, about 20 miles southeast of Great Falls, on the Neihart branch of the Great Northern road, and is the oldest coal-mining town in this region. About 10 miles west of Belt and about 10 miles from Great Falls are the two coal-mining towns of Stockett and Sand Coulee. At Stockett, the larger of the two places, is located the Cottonwood Coal Company, which is one of the two largest coal-mining companies operating in the district. Stockett has a population of about 800, composed largely of coal miners employed by the Cottonwood Coal Company. Sand Coulee, about 2½ miles northwest of Stockett, is a smaller mining town of about 400 inhabitants. It is situated in Straight Coulee, a branch of Sand Coulee, and owes its existence mainly to the Nelson and Gerber coal companies, which are operating at this place.

The other towns in the district are mainly supported by a ranch population. Chouteau, the most important of these and the county seat of Teton County, is located on Teton River, about 40 miles northwest of Great Falls. It has a population of about 400, and is bordered on the north by one of the oldest and best-developed irrigated districts in the Great Falls region. Along Sun River there are a number of small towns and trading points. The largest of these is Augusta, in Lewis and Clark County, on South Fork of Sun River, about 3 miles above its mouth. Sun River, somewhat smaller, although one of the oldest towns in this region, is located in Sun River Valley, about 20 miles west of Great Falls. Two towns have recently been laid out in Sun River valley by the Reclamation Service engineers—one at Fort Shaw Indian School, which will be known as Shaw, and another at the mouth of Sims Creek, which is called Sims. At Flowerree home ranch there is a large company store and another at Sunnyside, owned by the Sun River Stock and Land Company. Along the Great Northern Railway line the principal town within the area described is Collins, located on the north side of Teton River. From this place stage lines connect with Chouteau through Farmington, a post-office and store in the middle of Burton Bench. Bynum, another small trading point, is located in the northwest part of Burton Bench.

There are no towns along Missouri River below Great Falls within the area described, but above that town are two small stations, Ulm and Cascade, the latter, located near the base of the Big Belt Mountains, with a population of about 200. It is supported by a large ranch trade from each side of the river.

On Smith River there is a post-office known as Truly, about 5 miles above its mouth; another, Orr, farther up the river, has recently been discontinued.

In Belt Creek valley, about 2 miles above Belt, is the small town of Armington, which is situated at the junction of the new Billings and Northern and the Neihart branch of the Great Northern. It is mainly a small railroad town, which receives a portion of the ranch trade of the surrounding country. Along the new railroad there are a few small stores, located at intervals of 12 to 15 miles; these are Spion Kop, Geyser, and Stanford, the latter being an important trading point for a large ranch district along Skull, Running Wolf, and Sage Creek valleys.

While the Great Falls region is at present a sparsely settled district, it is believed that the Government irrigation projects now under way which will reclaim millions of acres of fertile farming land, the almost unparalleled advantages for the development of water power, and the increasing railroad facilities will cause the population to increase rapidly within the next decade.

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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

WATER-SUPPLY PAPER 222

PRELIMINARY REPORT

ON THE

GROUND WATERS OF SAN JOAQUIN VALLEY, CALIFORNIA

BY

WALTER C. MENDENHALL

WASHINGTON
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PRELIMINARY REPORT ON THE GROUND WATERS OF THE SAN JOAQUIN VALLEY.

By W. C. Mendenhall.

INTRODUCTION.

The agricultural situation in that part of the United States known as the Southwest is peculiar in that within it consumption tends constantly to exceed production. This is due to the large areas of desert, unsuited for agriculture but supporting many other industries. The entire irrigated acreage in the 11 arid States lying for the most part west of the crest of the Rocky Mountains was 7,539,545 acres at the time the Twelfth Census was taken in 1889. Since that date the irrigated acreage has been greatly expanded, and through the operation of the reclamation law and the impulse given by it to private enterprise that expansion will continue; but the population also has grown, and this growth in the future will be even more rapid than it has been in the past.

In the States of Nevada, Arizona, and New Mexico the mining industry becomes yearly of greater importance, and the influx of people engaged in it is increasing correspondingly. The growth of trade with oriental countries and the development of the mineral resources of Alaska have resulted in great accessions to the population of Pacific coast seaports, particularly those about San Francisco Bay and Puget Sound, and in greatly increased demands for food products. Southern California, as that portion of the State lying south of the Tehachapi Mountains is called, is receiving rapid recognition as a playground for the people of the entire United States, and of the thousands of tourists who visit this area each year many become permanent residents.

Of the areas in the Southwest within which food products for its cities, its tourist centers, and its mining regions must be raised, the largest and most promising is the interior lowland known as the Great Central Valley of California. The southern segment of this lowland,

the San Joaquin Valley, contains 7,360,000 acres, of which but 750,000 were under irrigation in 1899, and probably not more than 1,125,000 acres are irrigated at present. Southern California contains a million acres of land that would be cultivable if water were applied to it; yet in this region, where all the water resources are utilized, but 225,000 acres are under irrigation, and the remaining area is nonproductive or yields only a small and uncertain crop through dry-farming methods.

Furthermore, the density of population in the irrigated valleys south of the Tehachapi means the consumption there of practically all the staple food products raised. Fruits, especially the citrus varieties, are grown for export, and in some years more grain is produced than is necessary for local needs; but in general the demand in this area for food staples is in excess of the local supply.

The Imperial Valley, in southeastern California, promises to become a very productive area through the utilization of Colorado River water, and many other sections might be mentioned whose acreage will increase the total area under irrigation, but all of them together are smaller than San Joaquin Valley, which, with that of the Sacramento, must become the chief agricultural district of the Southwest.

The agricultural development of this valley is controlled by the distribution of rainfall, the character of the soils, and the possibility of applying other water than that which reaches the valley as a direct result of precipitation upon its surface. Its extreme southern end, in the vicinity of Bakersfield, is strictly arid, the average rainfall there being less than 5 inches. Precipitation increases gradually toward the north, until at Red Bluff, in the northern end of Sacramento Valley, the annual rainfall averages 25.7 inches. Intermediate areas receive an amount of precipitation intermediate between these two extremes; but south of San Francisco Bay the available records indicate a rainfall of less than 16 inches, and over the greater part of this area of less than 12 inches—an amount that is insufficient to insure crops, even of grain, and is entirely inadequate for the other diverse food crops which a dense population demands.

The progressive increase in aridity from the northern toward the southern end of the valley trough prevails to an equally marked extent east of the valley, in the mountain areas from which its surface waters are drawn. The total run-off from the Sierra, according to the best available records, is about 11,500,000 acre-feet annually. Of this amount, 3,000,000 acre-feet are supplied by the streams from Kings River southward and 8,500,000 acre-feet by the streams north of Kings River. The combined drainage area of the streams from Kings River southward is 5,143 square miles; that of the streams north of Kings River is 7,543 square miles. That is, a southern portion of the Sierra, whose area is nearly seven-tenths as large as the

northern portion, yields but one-third as much water in the form of stream discharge. Hence in the south end of San Joaquin Valley the acreage which is irrigable by the use of surface waters is very much less than that in the northern end of the valley, and the area available for development here is correspondingly greater than that available farther north.

The question of water supply is, of course, not the only one that confronts those who desire to see the development of the San Joaquin Valley proceed rapidly, although it is properly regarded as the most pressing. The quality of the soil, particularly with reference to the presence of hardpan or of alkali, is of the utmost importance. Extensive alkaline areas exist along the axis of the valley and part way up its eastern slope, especially at points where the ground waters lie close to the surface, and hardpans of at least two types underlie some of the higher and otherwise most valuable lands. These soil problems are being studied systematically by the soil experts of the Department of Agriculture[a] and the reports that are issued should be supplemented as rapidly as possible, until definite information as to soils is available for the entire valley.

CONDITIONS LEADING TO THE PRESENT INVESTIGATION.

The conditions already outlined—namely, the great actual and the much greater prospective importance of the San Joaquin Valley as an agriculturally productive center—have led during the last decade to greatly increased interest in the possibility of adding to the acreage under irrigation, and hence to the output in food products.

Irrigation enterprises, like those of other industries, invariably pass through a pioneer stage, in which only the most easily accessible resources are utilized. In this stage the methods of application of water are wasteful, the land holdings are large, and the agricultural output is low. Only later, when the population becomes much more dense and the need of greater output is clearly recognized, do methods so improve that the ratio of output to area, to resources, and to investment becomes such as to satisfy economic demands.

In Southern California irrigation methods have been carried to a greater degree of refinement than in any other section of the United States. When irrigation began here, during the first third of the nineteenth century, short, crude ditches were constructed by which the waters utilized were diverted from the lower courses of the streams to near-by lands upon which they were turned, and the only products were grain and pasture, by which the flocks and herds were

[a] Lapham, Macy H., and Heileman, W. H., Soil survey of the Hanford area, Cal.: Full operations of the Bureau of Soils for 1901, U. S. Dept. Agr. The results of similar surveys are available for areas about Bakersfield, Fresno, and Stockton.

carried through the dry season. Such methods were in vogue until the late sixties and early seventies, when American settlers entered the country and attempted to utilize lands that had been regarded as entirely worthless. These settlers brought with them capital, and constructed their ditches on higher lines and in a much better manner than did the old Spanish zanjas. They applied water much less lavishly, to larger areas, and with much better unit results, and so by continued improvements of this type all of the surface waters were finally utilized to the best advantage. But settlers continued to flock to the region, and attention was then turned to the underground waters, which were developed at first only to supplement the surface supplies. Such reservoir sites as were available were also filed upon and made use of, and eventually many enterprises were started, some of which depended on a combination of surface and underground waters, and others on underground waters alone. Still later refinements resulted in the reconstruction of many of the old ditches, the replacement of open canals by underground pipes, and the elimination thereby of waste by seepage and evaporation. In the lower lands wells were drilled which yielded flowing water, and stream waters which had previously been utilized on these lower lands were diverted to the bench lands, where products of higher value could be grown.

As a result of this intensity of development it is probable that in no area in the United States are the waters so thoroughly utilized as in the region that lies south of the Tehachapi Mountains. In their passage from the mountains, where they originate in precipitation, to the sea, where they are lost, some portions of these waters are used as many as eight times—in power plants, in irrigation from surface streams, and finally by the recovery of that portion of the surface flow which, sinking in the alluvial fans, augments the supply in the underground reservoirs.

Much of the San Joaquin Valley is still in the pioneer stage of irrigation development, depending almost exclusively on surface waters, and in a large part of the area waste is great, over-use is the rule, and, as a consequence, minimum production results from a maximum use of water. But the pioneer stage is passing. Engineers trained in more refined methods are entering the region and applying their training. Special communities, like those about Portersville and Lindsay, where citrus fruits are raised, have for a decade or more used deep underground waters, whose cost greatly exceeds that of surface waters where the latter are available in other parts of the valley. This relatively high cost is amply justified, however, in the citrus belt by the great value of the products.

In other parts of the valley, as, for example, in the neighborhood of Corcoran, capitalists who had profited in other regions through the use of flowing artesian waters have undertaken to develop colonies by

utilizing waters of this type, whose existence had been proved years before by the owners of large cattle ranches, who had put down wells to obtain water for stock.

In still other districts, as about Bakersfield, Stockton, and Fresno, isolated individual pumping plants have been installed within the last decade, and by their use lands whose owners had been unable to secure rights to the limited supply of surface waters have been brought within the productive zone.

These more or less isolated experiments and their successful outcome have resulted in a widespread recognition of the fact that the productivity of the San Joaquin Valley can be greatly increased by the utilization of the heretofore neglected ground-water resources. This recognition has been followed logically by a desire for specific information as to the quality, occurrence, accessibility, character, and proper use of waters of this type. In response to this demand the Reclamation Service, in 1905, before its separation from the Geological Survey and erection into a separate Bureau of the Department of the Interior, determined to investigate the ground waters of the valley, with the hope that it might become possible to establish there a reclamation project whose water supply should be obtained from the underground reservoirs. Similar investigations were conducted in other parts of the United States during the first three or four years after the passage of the reclamation act, and as a result of these investigations the energies of the Service were concentrated upon those projects which it found most practicable.

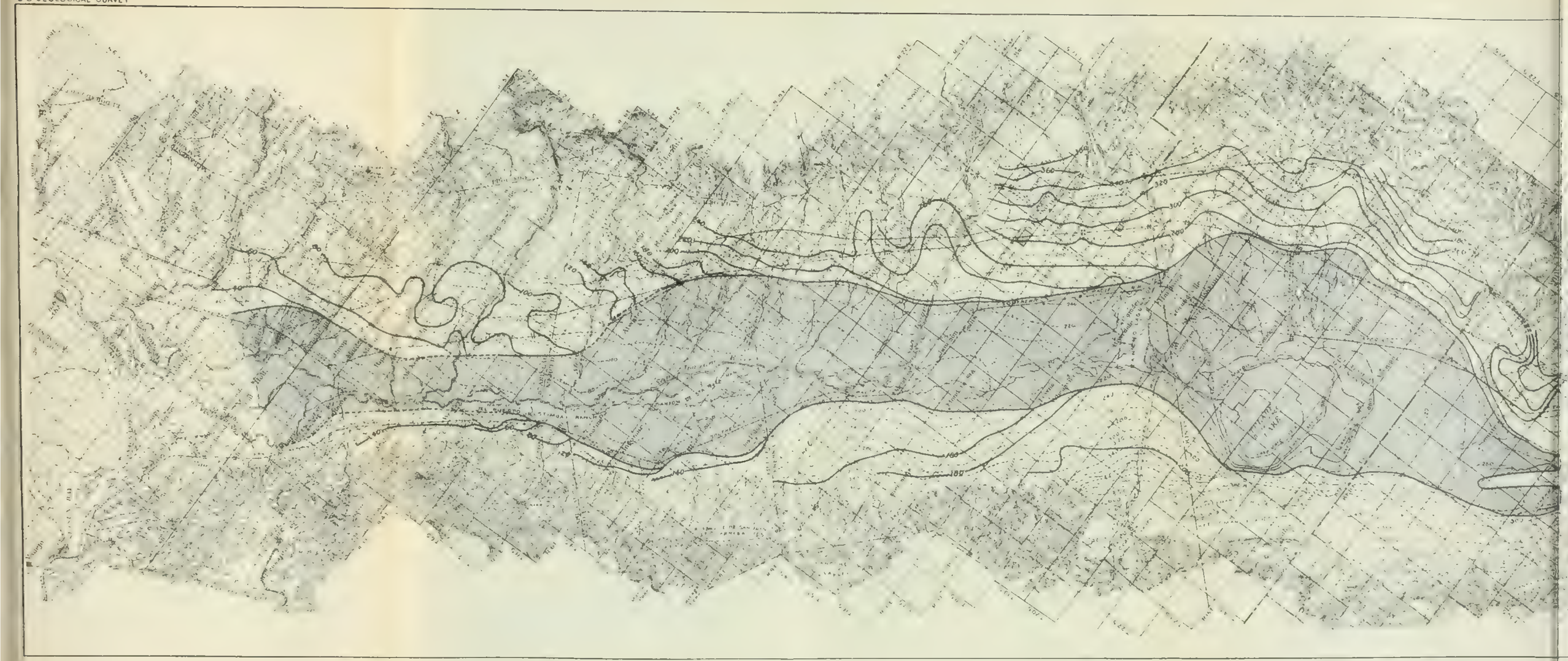
The San Joaquin Valley did not afford one of these most practicable projects, and the investigations begun there by the Service were terminated; but the work already carried out had given some idea of the wide extent, the easy accessibility, and the high quality of the underground waters in many parts of the valley, and the Geological Survey decided to continue the work begun by the Reclamation Service. As the appropriations available for this work have not been sufficient to permit it to be carried through in a continuous and systematic manner, its progress has been greatly interrupted, and there has been much delay in the preparation of results.

In the spring of 1905 A. J. Fiske, R. M. Priest, and S. M. Smith were assigned to work in the valley and spent about two months preceding the 1st of July in the collection of preliminary data. The work was resumed in the spring of 1906 by W. N. White and H. R. Boynton, jr., and was continued during the summer of 1907 by Mr. White, who, before the close of the year, had completed the collection of data on the flowing wells, pumping plants, and on many of the domestic wells throughout the valley. During about the same periods H. R. Johnson had been assigned to carry out a geologic study about the borders of the valley, in order to determine its structures,

in so far as they might bear upon the occurrence of the ground waters of the valley proper.

Much remains to be done in order that satisfactory data may be procured on all phases of the ground-water problems in the great area and reliable conclusions reached from the study of these data. More definite knowledge is needed as to the cost of developing ground waters under all conditions; the distribution of the alkaline waters that can not be used safely either for drinking purposes or for irrigation is not known with sufficient definiteness; and estimates are needed as to the costs of placing San Joaquin River waters on the arid west-side lands that would be so highly productive could they be irrigated. Nevertheless it seems advisable to issue a preliminary report at this time in order to make available such facts as have been gathered and to call attention to the ground waters as a resource whose more general use will probably be the largest single element in the future development of the valley. Especially will the installation of small pumping plants by individual landowners, who will thereby control their own water supplies, prove of great importance in the future.

A single small-scale map (Pl. I) accompanies this report. In its preparation, the topographical and engineering map of the San Joaquin Valley issued by the California State engineering department in 1886 was used as a base. Some slight additions and corrections have been made as a result of later surveys, but the earlier map has been used substantially in its original form. Upon this base the area in which flowing wells may be obtained has been outlined with as much accuracy as the information at hand permits. Beyond the limits of the artesian area the attitude of the ground-water plane has been indicated by hydrographic contours, which are based on the elevations of the surface as indicated by the topographic sketch contours of the base map. Neither set of contours is accurate in detail, but it is believed that the relations between the two—that is, the depths to ground water at various points—are correct within a reasonable margin of error, so that the map will be of practical value. It must be remembered, in using this map, that ground-water levels do not everywhere remain constant. On the deltas and in the irrigated areas there is a more or less regular annual variation in level, the plane of saturation rising during the high-water period—the period of maximum irrigation in early summer—and falling during the low-water period in the autumn and early winter. In the past there has been a marked permanent rise in the ground-water level in areas to which water has been applied by the construction of the large canals of the greater irrigation systems. This rise still continues in some localities, to which water has been applied for a number of years, and it will be marked in regions to which canal systems may be extended in the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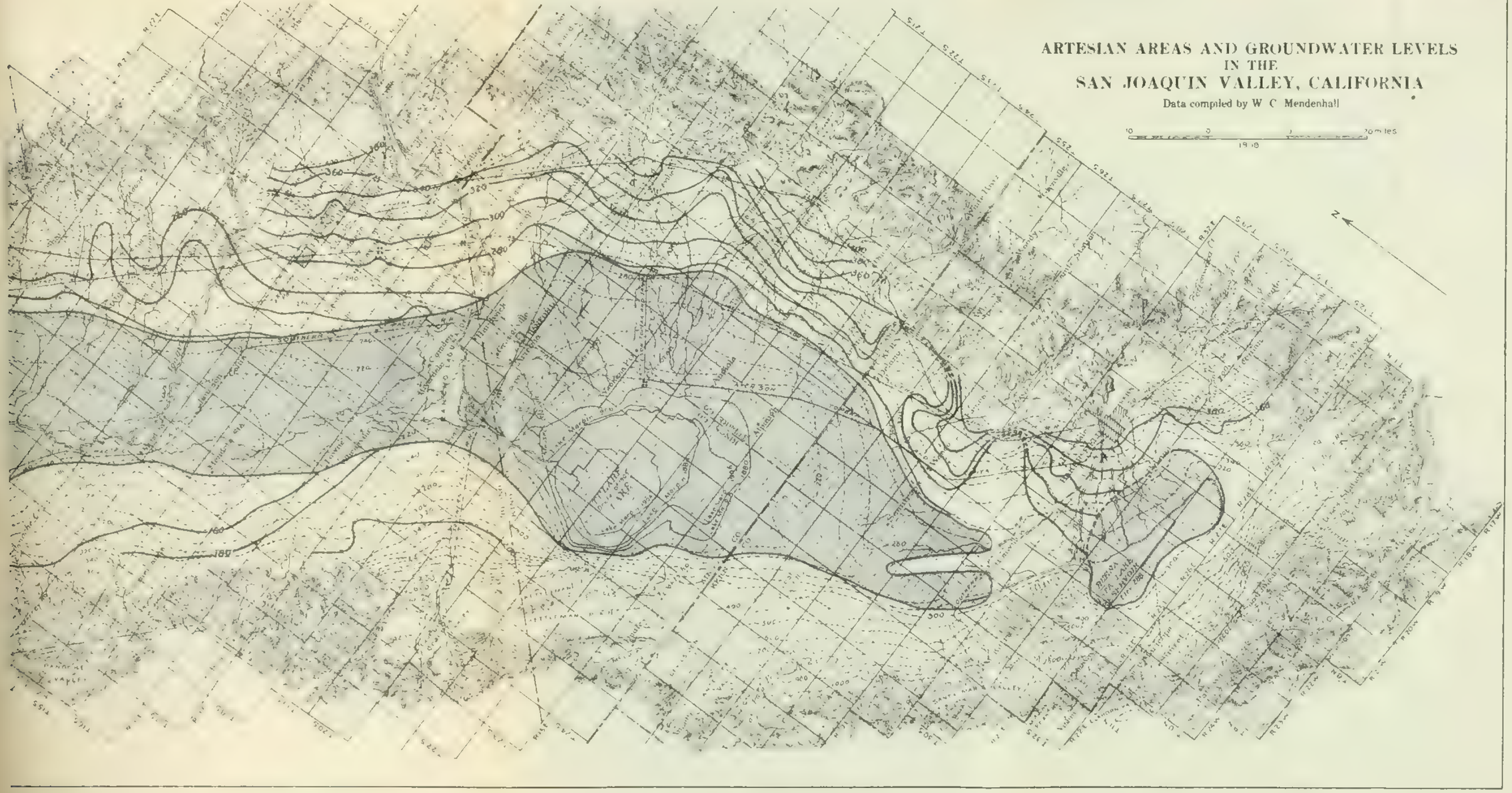
ARTESIAN AREAS AND GROUNDWATER LEVELS
IN THE
SAN JOAQUIN VALLEY, CALIFORNIA
Data compiled by W. C. Mendenhall
10 0 10 20 miles
1918
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LEGEND
Artesian areas
Hydrographic contours

future, although the chief changes of this character have doubtless already been brought about. In one or two limited areas there is probably also a general decline in ground-water levels. It is not possible, of course, to indicate a varying water level by a single set of hydrographic contours. Those used indicate about the position and form of the water plane in the period from 1905 to 1907.

GEOGRAPHY OF THE VALLEY.

San Joaquin Valley and Sacramento Valley together constitute the Great Central Valley of California, with an area of nearly 16,000 square miles. This level-floored depression is more than 500 miles long and varies from 20 to 50 miles in width. East of it the Sierra rises to between 14,000 and 15,000 feet above sea level, and west of it the lower coast ranges separate it from the Pacific. The greatest elevation of the Sierra is near its eastern edge and all its important drainage is westward toward the Great Valley, an important fact upon which the greater part of the actual and prospective agricultural value of the valley depends. The coast ranges are a series of parallel ridges of moderate elevation that inclose valleys, like those of the Salinas and Santa Clara, which, when not too arid, are highly productive.

The Great Valley itself exhibits little diversity in its physical aspect. Such differences as exist between its north and south ends are climatic, or, if physical, are directly due to climatic differences. Among local physical features based upon climatic differences may be mentioned the Tulare basin at the south end of the San Joaquin Valley, due to the aridity of the region and the consequent extensive development of alluvial fans. Two of these, extending from Kings River on the east and Los Gatos Creek on the west side of the valley, have coalesced in a low ridge south of which lie the Tulare Lake and Kern Lake depressions. Basins different in character and situation, but originating nevertheless in climatic conditions, are the overflow basins of the Sacramento and the lower San Joaquin valleys, of which the Yolo basin may be mentioned as a type. These basins occupy the lowest portions of the flood plains just outside the ridges that form the immediate river banks.

The central valley opens to San Francisco Bay and thence to the Pacific through Carquinez Straits and the Golden Gate, and the combined drainages of the Sacramento and San Joaquin systems discharge through these gateways. Other passes, like the Tehachapi, the Tejon, and Walker Pass near the south end of San Joaquin Valley, and the Livermore Valley gateway near Carquinez Straits, exist through the mountain barriers that surround the central lowland, but they are not as low nor as pronounced as the central tidal gateway. In general it may be said that the Great Valley is completely inclosed except for this opening.

The larger lobe of the central depression, extending southward from Cosumnes River and Suisun Bay, is generally known as San Joaquin Valley, although it is not all drained directly by San Joaquin River and its tributaries. The southern more arid third of the depression, extending from Kings River delta to the Tehachapi Mountains, has no surface outlet under normal conditions, and the surface waters accumulate in the Tulare Lake depression and the Buena Vista reservoir. Originally Kern Lake received a portion of the excess from Kern River, but through the protection afforded by a restraining dike water is kept out of it except as unusual floods may break the restraining dam, and the original lake bottoms have become valuable wheat lands.

The streams that drain into the valley from the Sierra carry practically all of the water that reaches it. They are in every way more important than those that enter it from the west. They have larger drainage basins, individually and collectively; they have longer courses; and they flow from higher mountains, with a much greater rainfall and a better protective covering of forest and brush; hence their discharge is many times greater and much less erratic than that of the west-side streams.

The total drainage area[a] tributary to the valley from the Sierra is 16,089 square miles; from the Tehachapi and Coast ranges 4,293 square miles, and the area of the valley floor is 11,513 square miles. The total area of the San Joaquin basin is therefore 31,895 square miles.

The average run-off of the principal east-side streams north of Kings River, with a combined drainage area of 7,543 square miles, is about 8,500,000 acre-feet, while that of Kings, Kaweah, Tule, and Kern rivers, discharging into the Tulare basin from a watershed with an area of 5,143 square miles, is about 3,000,000 acre-feet. The total discharge into the valley from 12,686 square miles of Sierra watershed is therefore about 11,500,000 acre-feet.

The preponderance of east-side streams has given the valley floor its well-marked unsymmetrical form. The valley axis, the line of lowest depression, is throughout much nearer the western than the eastern foothills. In places it lies against these hills, but elsewhere, as between Los Gatos and Cantua creeks, the west-side slopes are 15 or 18 miles wide, at least one-half as wide as those of the east side. They are also steeper than those of the east. Grades of 20 or even 40 feet to the mile are not rare, and it is unusual for the grades to be less than 6 or 8 feet per mile. On the east side 30 feet to a mile is about the maximum gradient, while 5 feet or less is perhaps the average.

[a] Hall, William Ham., Physical data and statistics of California, pp. 396 et seq.

These conditions are due directly to the fact that the valley floor has been built up by the alluvial material eroded by the streams from the mountains east and west of the depression and deposited in it. The larger and more active streams build flatter but more extensive alluvial fans--the type that makes up the east-side slopes; the more erratic and torrential streams of smaller volume build the steeper and less extensive fans that constitute the west-side slopes.

GEOLOGIC OUTLINE.[a]

THE ROCKS OF THE VALLEY BORDERS.

In simplest outline, the geology of the eastern border of San Joaquin Valley consists of the "Bedrock series" of granites and metamorphic sedimentary and igneous masses of pre-Cretaceous age, overlain at the north and south ends of the valley in an interrupted band occupying a zone of low relief between the Sierra proper and the valley proper by a series of Tertiary sediments, entirely unaltered and including beds as old as the Eocene, although the great body of the material seems to be Miocene or Pliocene in age. Between San Joaquin River and Portersville this zone of late sediments is missing, and the sands and gravels of the valley proper lie upon the flanks of the Sierran granite and metamorphic complex. Because of this hiatus the east-side Tertiary is separated into two bodies, of which the northern extends from Fresno River nearly to the Cosumnes, and the southern, conveniently designated as the Bakersfield area, extends from Deer Creek to the Cañada de las Uvas.

The northern area of Tertiary rocks, which is chiefly in the Milton-Merced regions, includes a lower, clayey series that has been called the Ione formation, a middle zone of andesitic sandstone, coarse volcanic breccias, and tuffaceous beds, and an upper gravelly series that is in places auriferous. This upper series usually occurs along the most westerly foothills and merges at many points with the gravels and soils of the valley floor.

The southern area consists of alternating beds of soft sandstone, clay, and gravel, the uppermost beds being coarse, like those of the northern area, and scarcely distinguishable in some places from the alluvium of the valley itself.

The geology of the western margin of the valley contrasts in many ways with that of the eastern border. The oldest rocks of the Mount Diablo Range—the easternmost of the coast ranges—comprise a series of altered igneous and sedimentary rocks known as the Franciscan series, which extend along the axis of the range from a point southwest of Coalinga to San Francisco Bay. Overlying them

[a] Abstract from a manuscript by H. R. Johnson, on the geology of the borders of the San Joaquin Valley.

on the valley side, but not continuously, is a series of sandstones, shales, and conglomerates of Cretaceous and oldest Tertiary age. Succeeding these in turn is a variable series, locally of great thickness and usually but not always present in some of its members, representing the Neocene—that is, the middle and upper Tertiary. These rocks, like the older sediments beneath them, are sandstones, shales, and conglomerates, but usually they are less firmly indurated than the Eocene and Cretaceous rocks. They overlie the latter unconformably and contain many unconformities within themselves, with a resulting variability in thickness and irregularity in extent of individual beds. This series contains the siliceous shales generally spoken of in literature as the "Monterey," besides a great variety and abundance of sandstones and conglomerates. Toward the top of the series are beds that clearly represent fresh water or subaerial deposition, undoubtedly much like that which is now taking place in Tulare lake and in the west-side alluvial fans. As a whole the sedimentary series dips toward the valley, although interruptions like the anticline of the Kettleman and McKittrick hills in places vary the prevailing monoclinal dips. In general the structures of the valley border are more complex at the south end than along the middle portion and at the north.

The valley as a whole is a great structural trough and appears to have been such a basin since well back in Tertiary time. Since it assumed its general troughlike form, gradual subsidence, perhaps interrupted by periods of uplift, has continued and has been accompanied by deposition alternating at least along what is now its western border with intervals of erosion. This interrupted but on the whole continuous deposition seems to have been marine during the early and middle Tertiary; but during the later Tertiary and Pleistocene, when presumably the valley had been at least roughly outlined by the growth of the coast ranges, fresh-water and terrestrial conditions became more and more predominant, until the relations of land and sea, of rivers and lakes, of coast line and interior, of mountain and valley, as they exist now, were gradually evolved. As these conditions developed, the ancestors of the present rivers probably brought to the salt and fresh water bodies that occupied the present site of the valley and its borders, or, in the latest phases of the development, to the land surface itself, the clays, sands, gravels, and alluvium that subsequently consolidated into the shales, sandstones, and conglomerates of the late Tertiary and Pleistocene series, just as the present rivers are supplying the alluvium that is even now accumulating over the valley floor.

The very latest of these accumulations are the sand and silt and gravel beds penetrated by the driller in his explorations for water throughout the valley. They are like the early folded sandstones,

shales, and conglomerates exposed along the flanks of the valley, except that they are generally finer, are not yet consolidated or disturbed. The greater part, perhaps all of them, accumulated as stream wash on the valley surface or in interior lakes like the present Tulare Lake, but a proportion of the older sediment that is greater as we delve farther back into the geologic past accumulated in the sea or in salt bays having free connection with the sea. It is these very latest geologic deposits, saturated below the ground-water level by the fresh water supplied chiefly by the Sierran streams, that constitute the reservoirs drawn upon by the wells, whether flowing or pumped, throughout the valley.

The chemical characters of the ground waters, as well as their occurrence and accessibility, are related to geology. If the valley alluvium is derived from the Cretaceous and Tertiary beds of the coast ranges, rich in gypsum and other sulphates and carbonates which are relatively easily soluble, the ground waters that percolate through it will soon dissolve large quantities of the salts. If the alluvium, on the other hand, is derived from the granites and metamorphic rocks of the Sierra, whose potassium, sodium, and calcium compounds are in the form of resistant silicates, the ground waters dissolve out these constituents slowly and under all ordinary conditions remain quite free from salts.

Obviously if the sands and gravels through which the ground waters percolate were deposited under such conditions that salts were deposited with them, as in the salt water of the sea or of bays like San Francisco Bay, or in interior lakes that are saline through evaporation, as is true of Tulare Lake, then the ground waters themselves will quickly become saline, although when they leave the mountains as surface waters, before their absorption by the alluvial fans, they may be as pure natural waters as are known in the world.

ORIGIN OF THE PRESENT VALLEY SURFACE.

The lowland through the heart of California known as the Great Valley, whose origin as a depression appears, in accordance with the facts just outlined, to date well back into Tertiary time, owes its actual surface to more recent action and to more obvious agents. That surface is, in brief, a combination of the surfaces of a great number of alluvial fans, originating at the mouths of the canyons through which the tributary streams discharge from the mountains into the valley.

Each stream that enters the valley brings with it from the mountains a greater or a smaller quantity of sand, gravel, or bowlders. All or a part of this burden is deposited in the valley, and the deposit constitutes the alluvial fan of that particular stream. The apex of each fan is the mouth of the stream canyon. From this apex it

broadens and flattens until it coalesces at its periphery with other fans. The stream that built it usually spreads delta-wise over it, discharging through a number of diverging channels into the trough of the valley. As a rule these spreading distributaries flow upon the surface of the fan, but some of the major streams from the San Joaquin northward are incised into the valley floor in shallow trenches 100 feet or less in depth. This must be due to special conditions, such as recent change in volume of stream flow or in elevation of the land relative to the sea—conditions not yet understood.

The fans of different portions of the valley indicate by their mass and form the conditions of volume and distribution of rainfall under which they originated. The west-side fans, particularly those in the middle of the valley and near its southern end, are steep and symmetrical, forms characteristic of areas of low rainfall very irregularly distributed. The east-side fans are of much greater mass and lower slope because the rivers that built them have a greater flow of somewhat less irregular character. The Kern River fan has grown westward against the McKittrick hills until it has isolated the Buena Vista basin south of it. Before dams had been built, interfering with the natural conditions here, a shallow lake occupied the present site of Buena Vista reservoir and the old bed of Kern Lake, and during seasons of unusual rainfall there was overflow northward toward Tulare Lake. The basin occupied by Tulare Lake is likewise due to the aridity of the valley and the consequent development of the Kings River and Los Gatos Creek fans. South of the low, broad ridge due to the coalescing of these two fans is the Tulare basin, in which a part of the surplus waters of the streams south of it accumulate. As a consequence of the flatness of this basin and the very erratic character of the supply that reaches it, the lake fluctuates widely in area during a series of years.

Northward from Tulare Lake basin the discharge of the streams is sufficiently great and sufficiently constant to prevent the formation of delta-dams like those formed by Kings River and Los Gatos Creek fans, and an open channel is maintained from the San Joaquin northward to Suisun Bay.

Along the lower course of the San Joaquin, conditions resemble those in the Sacramento Valley, i. e., they are the conditions usual along rivers draining humid rather than arid regions. Large areas are subject to regular annual inundation during the spring floods or are protected from this inundation only by the construction of artificial levees. The greater part of the water that inundates this area is supplied by the Sacramento system, but the greatest overflow occurs when the floods appear in the two systems at the same time.

The essential fact as to the present valley surface is that it is a direct result of stream action. It has everywhere been built up by deposition from the streams or from the fluctuating lakes that are

themselves dependent upon the streams; and it is formed of materials brought by the streams from the mountainous portions of their drainage basins where they are eroding instead of depositing Throughout the south end of the valley its surface is a combination of alluvial fan surfaces; at the north end of the valley these fans, less strikingly and typically developed because of the greater precipitation there, still predominate along the valley borders, while the center of the valley is a flood plain of the usual type.

SOILS.

As the valley surface has been molded by stream action into its present form, so the soils of the valley represent deposition by the rivers of materials washed out of the mountains from which they drain. This soil is modified in various ways after the streams have deposited it—by disintegration of the rock particles where the streams have left them, by the mingling of the products of vegetal decay where vegetation is abundant, or by chemical processes in place, such as the formation of hardpans or the accumulation of alkalies; but the soil foundation, so to speak, reflects pretty closely the type of rock outcropping in the drainage basin of the stream on whose delta the particular soils are found.

For example, the soils of the deltas of Kern and Kings rivers are in large part of granitic derivation, because granitic rocks form the greater part of the mountain drainage basin of each of these rivers. Their coarseness and the distribution of the coarse and fine phases are to a certain extent matters of accident, due to the location of present or past channels of the streams across their deltas; but in steep alluvial fans the coarser and more bowldery soils occur nearer the mountains. In the fans of those east-side streams from the Merced northward, whose lower courses at least are cut through late Tertiary formations containing a large percentage of lavas and derived products, other types of soil result.

The west-side streams, draining mountains practically free from granites and similar rocks but with soft serpentines, shales, and sandstones, deposit fragments of those rocks in their alluvial fans, and the result is a soil type entirely different from that of the east side and south end of the valley. These shale, clay, serpentine, and sandstone fragments disintegrate much more quickly than the granitic sands that contain large proportions of such resistant minerals as quartz and feldspar, and the result is the mellow, loamy soil with its fragments of siliceous shale that makes much of the west slope of the valley and is so productive whenever water can be applied to it.

Soil of another general class occurs at a few localities along the east side of the valley. This soil is not of alluvial fan origin, brought into the valley by the streams from the surrounding mountains, but is due to decay in place of the rocks underlying the particular area

where it occurs. Soils of this class are found northeast of Fresno beyond Clovis, and in some of the coves like Clark Valley north of Reedley, and perhaps in other foothill valleys in the Portersville-Lindsay district. Some of the rolling wheat lands found in a zone along the eastern border of Stanislaus and Merced counties may also be regarded as derived from the decay of rock in place rather than from inwashed alluvial fan material, but as the rock is itself a late Tertiary sediment differing but little from the alluvial fan material of the same area, the classification of the soils as residual rather than colluvial has no practical significance.

Another type of soil is neither more nor less than fine beach sand. This type is best developed in a zone surrounding Tulare Lake, and it represents the shore lines of that water body when it contained much more water than at present. In places this sand has been reworked by the wind—blown into inconspicuous dunes, as in the "Sand Ridge" near the Kings-Kern county line.

Finally, there are the soils of the "Tule lands" and the "Islands," the areas subject to overflow particularly along the lower course of the San Joaquin and its tributaries, but present, although less extensively developed, in other areas. These lands are black loams or adobes or impure peats, and are very fertile when reclaimed.

The Bureau of Soils of the Department of Agriculture has made detailed surveys of certain areas in the San Joaquin Valley as the beginning of a general soil mapping of the entire valley. The sheets at present available cover areas about Stockton, Fresno, Hanford, and Bakersfield, and others are in preparation. In the text of the reports and in the maps that accompany them, the soils are classified in great detail on a physical basis, and by a proper study of this classification the geologic origin of most of the soils may be traced.

Another task undertaken by the Bureau of Soils, of even greater immediate value, is the mapping of the alkalies. This work is designed to afford suggestions as to the management and reclamation of alkaline soils and prevention of the rise of the alkalies. When it has been completed for the entire valley it will be of great service in preventing sales of worthless lands to purchasers who buy in good faith with the idea of establishing homes. Many sales of this kind have been made in the valley, and any work that will tend to reduce their number is to be welcomed.

SURFACE WATERS.

The streams of the San Joaquin Valley and their characteristics have been referred to incidentally in the preceding pages. These characteristics depend upon the physical geography of south-central California and the control which it exerts over climate. All of the perennial and important streams flow from the Sierra.

Precipitation within the Sierra district depends upon altitude, latitude, and longitude. Up to a certain limit precipitation increases with increase of altitude; beyond that limit, which at the crossing of the Central Pacific is at Cisco, 6,000 feet above sea and 1,000 feet below the summit, precipitation decreases. Rainfall decreases also southward along the summit of the Sierra as well as in the valleys; and in those parts of the range, principally its southern portion, where altitude does not increase regularly from the western toward the eastern margin, so that the effect of longitude is not obscured by that of altitude, vegetation indicates less rainfall as the desert border of the range is approached.

Under these conditions, therefore, it is evident that the greatest discharge per unit of area will come from those streams with the greater proportion of their drainage basins farthest north in the high part of the Sierra but west of the summit.

From the tables of discharge for 1906, as published by the United States Geological Survey, in Water-Supply Paper 213, the following stream run-off in second-feet per square mile is taken:

Run-off of California rivers in second-feet per square mile.

Feather River	2.72
Yuba River	4.37
American River	4.29
Stanislaus River	3.63
Tuolumne River	3.33
Kings River	3.09
Kaweah River	2.93
Kern River	1.11

Data for the San Joaquin are not available. All these streams except Feather and Kern rivers occupy comparable positions on the western slope of the Sierra and drain the areas of maximum precipitation for their respective latitudes. The rather regular decrease southward from the Yuba to the Kaweah may therefore be assigned with confidence to the effect of latitude on precipitation. The drainage basins of both the Feather and the Kern extend into the very eastern part of the Sierra beyond the zone of maximum precipitation, and the inferiority of run-off from their basins as compared with that of neighboring streams may be assigned, in part at least, to the effect of longitude; i. e., their basins extend so far east as to be measurably affected by desert conditions. Altitude may also be a factor, since each of these streams drains portions of the range which are not so high as areas in the intermediate basins. The discharge of the principal east-side streams and the areas drained by each are summarized in the following table, compiled from the records of the State engineering department of California and from those of the United States Geological Survey.

The number of years of observations from which the average discharge was determined is also given. As several of these records are as short as five years, and one, that of the Kern, as long as seventeen years, it is obvious that they differ in value; but on the whole they supply a concrete indication of the average amount of water discharged into the San Joaquin Valley annually by its chief streams.

Discharge of streams from east side of San Joaquin Valley.

River.	Length of record.	Area of drainage basin.	Average annual discharge.
	Years.	*Sq. miles.*	*Acre-feet.*
Cosumnes	5	580	882,417
Jackson Creek	5	283	161,672
Mokelumne	8	657	1,640,057
Calaveras	5	491	739,396
Stanislaus	11	1,051	1,254,151
Tuolumne	11	1,500	1,011,452
Merced	10	1,076	1,113,754
Chowchilla	5	268	61,854
San Joaquin	12	1,637	1,972,145
Kings	16	1,742	1,790,187
Kaweah	6	619	401,954
Tule	9	437	199,444
Kern	17	2,345	670,611
Total		12,686	11,498,984

The high-water period of the Sierra streams comes during the late spring and early summer months, when the snow accumulated in the winter is melting most rapidly from the mountains; the low-water flow comes during the late summer and fall months after the snows are gone and before the winter rains have begun. These characteristics are illustrated in the following table of monthly discharge of Kings River for 1906, as determined by the United States Geological Survey:[a]

Monthly discharge of Kings River, 1906.

Month.	Discharge in second-feet.			Total in acre-feet.
	Maximum.	Minimum.	Mean.	
January	25,500	205	2,360	144,000
February	2,150	792	1,150	63,900
March	21,000	1,220	5,240	322,000
April	7,760	2,960	4,720	281,000
May	16,800	3,939	10,700	658,000
June	26,600	8,320	17,100	1,020,000
July	22,400	8,180	16,300	1,000,000
August	7,900	1,870	4,300	264,000
September	2,020	682	1,120	66,600
October	682	385	516	31,700
November	610	330	397	23,600
December	2,230	330	700	43,000

Each of the major streams discharges from the mountains upon the eastern edge of the valley in a single channel, but after reaching the valley it usually divides into a number of branches, thus spreading over its delta. This characteristic is most marked in the streams that flow into the southern end of the valley, for many of the northern

[a] Water Supply Paper 213, p. 159.

tributaries are incised in the valley floor and are thus confined between definite banks. This distribution is much more pronounced during the high-water period of early summer than at other seasons of the year. A main channel of sufficient capacity to carry the low-water flow proves inadequate during the flood period, and there is then overflow into the numerous subsidiary channels.

The natural habit of all of the main streams has of course been extensively modified by irrigation. Canal systems now take from the channels practically all of the low-water flow and an important percentage of the maximum early summer flow. These systems have been described by Grunsky.[a]

The west-side streams are practically negligible as factors in the San Joaquin Valley water supply. Only a few of them are perennial, and the late summer flow of these is so slight that a few acres at most can be irrigated by their use. A trifling amount of irrigation of this type is accomplished by utilizing the waters from Los Gatos Creek, Cantua Creek, and others.

UNDERGROUND WATERS.

VALUE FOR IRRIGATION.

Although the underground waters of the valley have been known and used in minor ways practically ever since its settlement, it is nevertheless true that the movement for their extensive utilization as sources of irrigation supply is a late phase of development, for many of the earlier attempts to make use of them resulted in failure.

Among the causes that have contributed to past failures may be mentioned: Application of the developed waters to poor lands, wasteful methods of application; dependence on the continuance of artesian flow; lack of adjustment to the greater cost of pumped waters as compared with that of the gravity waters upon which reliance has heretofore been placed; lack of intensive farming methods and of proper adaptation of crops to soil and locality; too large farm units; and, in a few cases, inadequate transportation facilities.

The most potent of all these causes has been the prevalence of the easy-going methods of the pioneer—the careless, wasteful habits that are a direct inheritance from the grazing and grain-raising period which has not yet passed from the valley. Land and such waters as are utilized have cost little heretofore in the San Joaquin Valley, and things that cost little are lightly valued, no matter what their intrinsic worth. This spirit is fostered by the immense holdings of some of the larger companies. Few of these companies practice intensive cultivation, though their lands are among the best in the valley.

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[a] Grunsky, C. E., Water Sup. Papers, U. S. Geol. Survey, Nos. 17, 18, and 19. These papers are no longer available for distribution, but they may be consulted in libraries.

Usually hay and grain are raised to feed through the dry season the stock that is in pasture during the grazing period. But although not as a rule intensely cultivated and by no means producing the maximum of food products or supporting the largest possible population, most of the large holdings are more carefully and successfully managed than the quarter section of the small farmer.

Despite all obstacles and discouragements, however, the use of underground waters is gradually extending. Special, high-priced products like the citrus fruits of the Portersville-Lindsay district justify heavy expenditures for production, and underground water has long been successfully used in this section. One of the highest lifts in the world of water for agricultural and horticultural purposes is that of the Badger Irrigation Company's plant at Exeter, with a maximum lift of 586 feet. This is an experiment, but the success of pumping water to great heights to irrigate the specially early citrus fruits of this region is fully demonstrated, the acreage devoted to these products is constantly extending, and the yield is increasing rapidly as groves planted recently approach maturity.

Irrigation by means of pumped underground water is also proving successful under the entirely different conditions that exist about Lathrop, Lodi, and Stockton, in San Joaquin County. About 200 small pumping plants are in operation in this county, the greater number of which have been installed within a few years. By their use alfalfa, vineyards, and varied crops of fruits and vegetables are successfully grown. Windmills also are extensively used, often with auxiliary gas engines attached to the same well. The area in which this type of irrigation is practiced is closely settled, houses are neat, prosperous looking, and well cared for, the villages and cities which supply the country trade and market the products are flourishing, and altogether there is every evidence of successful endeavor and abundant prosperity.

Still other communities whose existence depends upon the utilization of ground waters are the recently established colonies in Kings, Tulare, and Kern counties, of which the Corcoran settlement is a type. This particular locality is within the artesian basin, and a group of deep wells yield flowing waters which are utilized for all purposes. As a result, successful dairy farms have been established, sugar beets are raised, and a factory has been built for the manufacture of sugar from them.

It is thus evident that there is a gradual awakening to the value of the ground waters and their usability, although in many localities the advocate of the use of these waters is still met by the statement that they can not be developed and applied at a profit under agricultural conditions as they now exist. It is true that the pumped waters are

more expensive than the ditch waters, whose cost as a rule is very low. The average cost of the pumped water used by the Kern County Land Company near Bakersfield, with an average lift of 30 feet, is $1.29 per second-foot for 24 hours on the basis of a charge of 15 cents per horsepower per hour for electric current, whereas the cost of surface water in the same locality is 75 cents per second-foot for twenty-four hours; i. e., the pumped water costs 72 per cent more than the surface water. When it is remembered, however, that almost universally in the San Joaquin Valley water is used in great excess, to the immediate and ultimate injury not only of the lands to which it is applied but of adjacent lands; that on many of the delta lands there is as yet but little intensive cultivation, and that therefore the margin of profit is low; that there is an important proportion of large holdings and absentee ownership dependent upon inefficient hired labor; and above all that, in the midst of the communities in which it is asserted that pumped waters can not be profitably used in agriculture individuals may generally be found who are using them with striking success; when all of these things are taken into consideration, it may be asserted with confidence that the greatest increase in the agricultural development in this valley in the future will be brought about by a utilization of the ground-water supplies, whose development has only begun and whose value is as yet but faintly realized.

It will probably be true in the future, as it has been in the past, that side by side with successful attempts at the utilization of underground waters will be unsuccessful attempts, and that the general movement for full realization upon this asset will be checked here and there by conspicuous failures widely advertised. This is a condition that always arises in any general advance. Each failure should teach its individual lesson as to a particular way *not* to undertake development or to apply water, and should not be interpreted as an argument against the usefulness of the resource under proper conditions, for the fundamental facts remain that ground waters exist beneath the floor of the San Joaquin Valley in immense volume and that over wide areas they are of high quality and very accessible. They are certain, therefore, to be widely used in the future, and by their use hundreds of thousands of acres now arid and unproductive will be brought to yield handsomely.

The development of the ground waters under the conditions that exist at present, when the chief argument against them is their cost as compared with that of the surface waters which have set the standard should follow two or three lines.

In the first place, pumping plants in the higher parts of the delta lands should be used as adjuncts to insufficient gravity supplies. The

supply of the gravity waters during the flood months of May, June, and July is from 2 or 3 to 15 or 20 times that available during the months of August, September, and October, when many crops are maturing. As a consequence many owners of late rights to gravity waters secure a proportion of the flow during the early high-water period, but are left without it during the low-water period, when there is only sufficient to satisfy the earliest rights. Such owners often have enough gravity water for one or two early irrigations, but not more. Under present conditions, therefore, the maturing of late crops is a precarious matter with them, and they are confined practically to those products which will yield returns when irrigated only in the spring or early summer. This is a serious handicap, as it greatly limits the range of their agricultural activity and often condemns their land to idleness during half of the year. By the installation of pumping plants, to be operated only when gravity waters are not available, this handicap is removed, and yet the cost of irrigation is much less than where no surface waters are available and pumps must be operated continuously.

In the second place, in districts that have a market for garden products or for those special farm products whose value and yield justify some expense in their production, as sweet potatoes, celery, asparagus, or onions, the small land owner can well afford to install an individual pumping plant independent of surface supplies. The same method will be successful with crops that require only one or two irrigations a year, as, for example, some of the fancy varieties of grapes that are now raised so profitably in the northern part of the valley.

Another line to be followed in development is the utilization of flowing artesian waters. Along the axis of the valley is a zone with an area of about 4,300 square miles within which flowing waters are available. Over perhaps two-thirds of this area the flowing waters are sufficiently pure to be suitable for use in irrigation.

None of these lines along which it is suggested that ground waters may be used are experiments. Each has been followed successfully in some of the communities in the valley, although in other sections quite as favorably situated the investigator will be told that pumped or flowing waters can not be used profitably. Communities, like individuals, fall into ruts, acquire bad habits, and lose the power of initiative. In this condition they may overlook or fail to utilize some of their most valuable assets.

In the course of this investigation nearly 4,000 wells in the valley have been examined and data collected as to depth, yield, cost, etc. Among them are many flowing wells. For most of the wells the data

are incomplete, but from the records available the following averages have been determined:

Average size, depth, yield, cost, etc., of flowing wells.

County.	Number averaged.	Average diameter. (inches).	Depth (feet).	Yield (miner's inches).[a]	Average cost.	Annual interest on cost at 8 per cent.	Interest charge per miner's inch per year.
Kern	10	10	621	53.3	$1,545	$123.60	$2.30
Kings	7	9	1,037	30	2,555	204.40	6.81
Tulare	32	8	745	26	1,711	136.88	5.26
Fresno	7	8	936	20	1,540	123.20	6.16
Merced	16	7	350	5½	470	37.60	6.84

[a] A California miner's inch equals 0.02 second-foot.

These are actual averages based upon the experience of owners of wells already drilled and flowing. They therefore have a definite value as a basis for estimating costs of artesian waters to be obtained as a result of future developments. They may be compared with the charge made on the Kern delta for gravity water, namely, 75 cents per second-foot for 24 hours, equivalent to $5.47 per miner's inch per annum.

In comment upon the table it is to be said that the Kern County average is too low, because it happens that among the wells for which sufficiently complete data exist for computing these averages there were one or two of exceptionally great yield that have unduly raised the average yield and reduced the cost, thereby giving a figure lower than that which will probably be realized in future development.

It must be remembered further that the figures are based on the assumption that the entire year's flow will be utilized. This assumption can be realized only by the construction of reservoirs in which the water will be stored during the nonirrigating season for use when wanted. Such construction will add to the cost and will reduce the supply in three ways: (1) By a reduction of flow because of the increased height of delivery necessary to discharge into a reservoir; (2) through loss by evaporation from the surface of the reservoir; (3) through loss by seepage from the reservoir.

The uncertainty as to the amount that will be delivered by any artesian well is another disturbing factor in making exact calculations. The area within which flowing waters are procurable has been outlined with approximate accuracy, but the yield of any well can be determined only after the well has been sunk and the necessary capital invested in it. Some of the wells used in computations have delivered much more than the average supply and so have yielded exceptionally cheap waters; others have delivered less than the average, and their waters are correspondingly expensive.

Another condition that must be realized is this: When the number of wells drawing from the artesian supply is greatly increased in any particular neighborhood, the wells interfere and the yield of each is lessened. When the maximum acreage is dependent on artesian flow under these conditions, the installation of pumping machinery may become necessary in order to insure the continuance of an adequate water supply.

As against these disadvantages, which have been rather fully outlined, as is essential in any frank and therefore useful discussion, is to be placed regularity and relative constancy of the supply and its availability at all times, as compared with the fluctuations of surface waters unavailable except during the flood season to any but the owners of the oldest rights. An added advantage where the landowner owns his well is his complete control over his water supply. He may irrigate when and how he will, and thus most economically, and is not dependent upon the adjustment of supply among a number of users from a common source.

ORIGIN OF THE GROUND WATERS.

The ground waters of the San Joaquin Valley have precisely the same origin as its surface waters—namely, the rainfall and snowfall in the drainage basins tributary to the valley. They are in reality simply that portion of the surface waters that sinks into the sands and gravels of the valley floor and makes the rest of its journey seaward by slow percolation through the pores between the sand grains.

One of three things happens to the water that reaches the earth's surface as precipitation: (1) It returns directly to the air by evaporation from plant, soil, or water surfaces; or (2) it flows to the sea in surface streams; or (3) it sinks into the ground, and joins the body of water that saturates the soil particles below the ground-water level. It is with the latter part of the precipitation on the nearly 32,000 square miles of area included in the San Joaquin Valley and the mountain watershed tributary to it that we have to deal.

In the outline of the geologic history of the valley it has been pointed out that its entire surface is made up of the surfaces of contiguous alluvial fans, and that the valley is underlain to a depth that can not be determined accurately, but that doubtless runs into thousands of feet, by porous, unconsolidated, alluvial-fan material, mingled, in some areas, with lake deposits. This material has been transported from the mountains to the valley by the agency of running water. Many times its own volume of water has passed through and over it in the course of its removal from the mountains to the valley. It was deposited by and in water and has been more or less continuously saturated ever since.

A large but quite undeterminable portion of the run-off from the mountains each year sinks and joins the ground water. Of the 3,000,000 acre-feet discharged annually into the valley south of the Kings River–San Joaquin divide, only the small portion that spills northward from Kings River itself reaches the sea over the surface, because there has been no outflow from Tulare Lake for forty years. The greater part evaporates or sinks to join the underground supply. Northward from Kings River the surface waters are greater in volume than south of it and serve effectually to keep the sands and gravels beneath them saturated.

UNDERGROUND CIRCULATION.

Underground waters near the surface usually move slowly in the direction of the surface slope and at rates that vary with the gradient of the slope and the coarseness of the material through which they percolate. The freedom of the outlet by which they escape is also important. They may be ponded by a restricted outlet just as surface waters may. Measurements of rates of ground water movements in the San Joaquin Valley are not available, but facts stated in the following paragraph indicate pretty plainly the conditions that probably prevail:

(1) The alluvial fans that make up the valley floor are generally of low slope and fine material. The fans of the Cañada de las Uvas and of San Emigdio Creek, at the south end of the valley, and of Pala Prieta and Los Gatos creeks on the west side are exceptions; but the streams that have produced them contribute so small a proportion of the ground waters that they may be disregarded. (2) The general slope of the lowest line of the valley, from the south to the north, is not only not continuous, in that it is interrupted by ridges like that north of the Tulare basin, but it averages only about 1 foot to the mile, a very low gradient for a semi-arid region. (3) The wells drilled throughout the valley prove that the sediments underlying it are all fine. (4) The surface outlet of the San Joaquin and Sacramento drainage is by way of Suisun Bay and the straits of Carquinez to San Francisco Bay; but the straits are restricted, and it is not probable that bedrock lies far beneath the surface in their vicinity. In short, there is no adequate outlet for the underground waters of the Great Valley, which is canoe-shaped, with only a notch in the rim at the straits through which the surface waters spill. All of these conditions favor slow movement of the underground waters about the borders and at the ends of the valley, with their practical stagnation along the lower San Joaquin because there is no adequate outlet for them there. To be sure, capillarity and evaporation afford some slight escape for the ground waters as they approach the surface in their slow movement along the

valley axis. The great alkaline areas of the east slope and of the valley trough indicate escape of underground waters, because it is by this escape that the alkalies are concentrated at the surface; but the outlet provided in this way is of slight consequence when compared with the total body of ground waters.

The belief that there is little movement in the subsurface waters of the lower San Joaquin is strengthened by a consideration of their chemical characteristics. Some of the ground waters of the upper deltas of the east side are among the purest waters of this type known, while those from the shallow flowing wells of the bottom of Tulare Lake and from the deeper wells of the north end of the valley are so heavily charged with mineral matter as not to be potable or suitable for irrigation purposes. Ground waters dissolve the soluble minerals from the rock fragments—the clay, sand, or gravel particles with which they are in contact. The amount thus dissolved depends upon the chemical combinations in which the minerals exist, some being much more soluble than others, and upon the length of time during which the waters are in contact with them. In general, the alkalies in the sands and gravels of the east side are in the most resistant form, the silicates of the granitic débris from the Sierra; the alkalies of the sands and gravels of the west side are in less resistant form, the sulphates and carbonates of the Cretaceous and Tertiary shales and sandstones; hence the ground waters of the high parts of the east slopes of the valley, which move with comparative rapidity, are much purer than the waters from similar situations on the west side. Furthermore, the volume of water poured out upon the east-side fans is many times greater than that discharged upon the west side, so that the alkalies dissolved are greatly diluted. But down in the trough of the valley, especially near its north end, the ground waters contain a much larger percentage of salts, even than those of the west side. If there were rapid circulation of ground waters here, this condition should not exist, for the dissolved salts should have been gradually carried out. The fact that the waters are highly mineralized is regarded then as additional evidence of sluggish circulation, or perhaps practical stagnation.

QUANTITY OF GROUND WATERS.

Little need be said of the quantity of the ground waters in the valley for two reasons: The first is that although it is clear that the quantity is enormous, it is not possible to estimate it with any exactness; the second is that the actual quantity is not of as much importance in its use as its accessibility and the rapidity with which it is restored when withdrawn.

The area of the valley is about 11,500 square miles. The depth of the sands and gravels which are saturated with the ground waters is

probably not less than a mile at the maximum, and may be much more. The average depth is equally unknown, but wells 1,000 or 2,000 feet deep, or even more, that are scattered throughout the valley, do not reach the bottom of the unconsolidated sands and gravels; so it may safely be assumed to be one-quarter of a mile and more. At this depth, nearly 3,000 cubic miles are saturated with ground waters, and if the porosity is 20 per cent, the conclusion is reached that 600 cubic miles of water underlies the valley—certainly a conservative estimate. But this includes water of all qualities and those found at great depths. Not all of the former are usable and the latter are not accessible.

ACCESSIBILITY AND AVAILABILITY OF GROUND WATERS.

One of the most important elements in the cost of ground waters, of course, is their accessibility, by which is generally meant the depth at which they stand beneath the surface; but the depth of boring necessary to develop them and, if pumped, the amount that they are drawn down when the pumps are in operation are also important elements.

The cheapest waters in general are those that flow out at the surface, even though deep wells may be necessary to develop them and the initial cost may therefore be great. But these waters may not always be most available, because they are to be had only in the lower parts of the valley, where, because of climatic conditions and alkalinity of soil, many of the lands are less valuable than those farther up the slopes. Generally speaking, about the borders of the valley the ground waters lie at the shallowest depths in the deltas and at the greatest depths in the interareas. The flood channels and the irrigation ditches are the lines along which recharge of the ground waters is effected; hence in their vicinity the ground-water level lies near the surface and the pumping lift is at a minimum.

Beneath the west side slopes, unfortunately, where the waters are most needed, they are not accessible. The conditions here illustrate well the dependence of the ground waters upon local surface supply. Surface run-off is most limited in this area, the ground waters lie at too great depth for profitable utilization, and they are usually too inferior in quality to be desirable even for irrigation.

DEVELOPMENT OF GROUND WATERS.

The development of underground water in the valley is as yet in its infancy. It does not compare in intensity with that in Southern California, where, with an irrigated district of about 225,000 acres, there are nearly 3,000 flowing wells, costing about $675,000 and yielding nearly 200 cubic feet per second of water, and about 1,400

pumping plants in which $2,500,000 are invested, by which an average of nearly 300 cubic feet per second of water are produced. Other minor wells increase the investment, but add little to the product. The total estimated investment in the development of ground waters, exclusive of the distribution systems, is about $5,000,000 in this restricted district and the water produced is approximately 500 cubic feet per second. For comparison with this development south of the Tehachapi, the following estimates have been prepared from the records of the U. S. Geological Survey to indicate the relatively meager development in the San Joaquin Valley.

Ground water development in San Joaquin Valley.

County.	No. artesian wells.	Estimated cost.	Estimated yield, second-feet.	No. pumping plants.	Estimated cost, well and plant.	Estimated capacity, second-feet.	Estimated output.	Total cost.	Total yield.
Kern	112	$161,400	73.46	104	$138,632	225.84	½ capacity. 42.64	$300,032	116.1
Tulare	124	189,968	23.31	191	244,098	162.72	½ capacity. 54.24	434,066	77.55
Kings	77	112,959	19.3	3	1,530	1.34	½ capacity. .24	114,489	19.54
Fresno	40	40,000	7.5	28	.....	30	5	.....	12.50
Madera	31	13,237	7.81	17	44,931	40.8	6.8	58,168	14.61
Merced	133	48,013	7.95	43	46,700	40.93	6.82	94,713	14.77
Stanislaus	5	3,830	1	9	.....	8.35	1.39	.....	2.39
San Joaquin	....	.....	.....	202	123,836	250	41.67	.....	41.67
Total	522	569,407	140.33	597	599,727	759.98	158.80	1,001,468	299.13

The data upon which these estimates are based are neither as complete nor as satisfactory as those used in Southern California, and therefore the conclusions must be regarded as suggestive rather than as accurate in detail. As an example of one of the weak points in the estimates, attention may be called to the column in which the output of the pumping plants is recorded. Generally these plants are used in the irrigating of alfalfa or of garden products. Some of them are independent sources of water; others are auxiliary to gravity waters and are used only when the latter are not available; some are in the southern part of the valley, where the rainfall is less than 5 inches; others are in the northern part of the valley, where the rainfall is more than twice as heavy, and where on this account less water need be applied artificially. Of course the pumps are not in constant operation anywhere, but the percentage of the year that they are run varies with local conditions. No exact estimate of this percentage can be made, but it has been assumed in the estimates that the pumps are operated the equivalent of two months continuously, hence that their output for the year is one-sixth of what it would be were they in constant operation. This estimate is more likely to be too high than too low. In one county, Tulare, which includes the Portersville, Exeter, and Lindsay citrus districts, a larger

factor is used. Most of the pumps in this county are used for citrus irrigation, and it is assumed here that their output is one-third of what it would be were they in continuous operation. This estimate should not be excessive.

Accepting the estimates, then, as they are, we find that in the San Joaquin Valley there are at present between 500 and 600 flowing wells and a somewhat greater number of pumping plants, representing an investment of between $1,000,000 and $1,500,000, and yielding in the neighborhood of 300 cubic feet of water per second. The number of wells is about one-fourth that of Southern California, the investment is one-third, and the product about one-half, although the total irrigable area of the San Joaquin Valley is nearly ten times that of the southern field and the underground waters available are probably in similar ratio. This comparison, even though the figures upon which it is based are not complete, gives a graphic idea of the development that may yet be accomplished in central California by the full use of the ground-water resources.

COUNTY NOTES.

KERN COUNTY.

GENERAL CONDITIONS.

Kern County, which includes the extreme southern end of the San Joaquin Valley, receives its principal water supply, both surface and underground, from Kern River, which flows out upon the valley floor just above Bakersfield. Minor amounts, chiefly as winter flood waters, are contributed by Poso Creek and the streams that enter the valley from the south and west. The supply in excess of that used by the canal systems flows into Buena Vista reservoir, where it is stored for the irrigation of the Miller and Lux lands along the trough of the valley to the north. During seasons of particularly heavy stream flow, a portion of the water escapes northward along either the main channel or the Goose Slough channel to Tulare Lake.

In the course of its distribution over the delta lands through the canals in irrigation, and by flow through the natural distributaries, a definite portion of the water sinks and so maintains a condition of saturation of the sands and gravels that have been deposited in the course of the growth of the delta. These saturating waters, like the surface waters, move in the direction of the slope of the delta, but at a much slower rate. They circulate more freely through the coarser beds of the delta deposits, and as they pass beneath the finer beds that are more numerous in those parts of an alluvial fan that are most distant from its head, they accumulate pressure. Therefore when the confining beds above them are pierced by a well they rise,

and if the pressure is sufficient they flow over the surface. These are the flowing artesian wells of the Kern and Buena Vista lake beds and the region extending some miles north of them, and of the main San Joaquin Valley artesian basin, beginning in the neighborhood of Button Willow and extending thence northward down the San Joaquin Valley to the delta of the San Joaquin and Sacramento rivers. It may connect with the Buena Vista artesian area, although there is no evidence available now to determine this point.

FLOWING WELLS.

In 1905 there were 112 flowing wells in the county that were examined, and there were doubtless a few more that were not seen. The yield of these was in the neighborhood of 70 or 75 second-feet. About one-third of the wells were used for irrigation, the remainder being used for stock or domestic purposes or allowed to waste uselessly. The areas in which they occur are indicated by the outlines of the artesian basins, as shown on Pl. I.

Generally speaking, the artesian pressures have not been seriously affected by the developments that have taken place to date, although there are some wells, as in the Semi-tropic district, whose flow has decreased markedly as a result of the boring of big wells near by, but on lower ground and therefore in more favorable situations. Artesian wells usually deteriorate with age, as a result of any one of several causes, as slow filling with sand, clogging by gelatinous deposits, the growth of miscroscopic organisms, and, finally, by the deterioration of the casing.

The State engineering department of California measured the yield of certain flowing wells in the Kern delta in 1885, and some of these were remeasured in 1905. The remeasured wells show decreases in yield varying from 50 to 100 per cent, but in only one of the wells available for comparison has there been complete cessation of flow. Decrease in yield of individual wells as development progresses is so usual a phenomenon that no community can safely plan its future on the assumption that a cheap supply of this type will remain constant, even in such large basins as those of the San Joaquin. But flowing water should be available for years from those wells whose initial yield is sufficiently large to be of value. Later, when the communities are more thickly settled and the wells are so closely grouped that flow and yield are materially decreased, industrial conditions may have so changed that pumps can profitably be installed to augment the supply. The cost of such pumped waters will usually be particularly low because of the slight lift required to bring them to the surface.

PUMPING PLANTS.

More than 100 pumping plants in Kern County develop underground water for various purposes. Of these about 40 are gas plants, 25 are steam plants, and the rest are electric. The developed waters are used for irrigation, for city supplies, for engine waters, and as supplies for steam plants, as at the pumping stations of the Pacific Coast Oil Company.

In the district about Bakersfield 50 pumping plants are in use to develop irrigation water. Half of these are electrically operated and belong to the Kern County Land Company. Each of these plants is equipped with 30 or 40 horsepower motors directly connected with No. 8, 10, or 12 centrifugal pumps. Each pump is connected with from three to five 13-inch wells, the number being determined by the yield of each well. From the data collected on these wells, the following cost averages were computed, on the basis of the quoted charge of 15 cents per horsepower per 24 hours, for the electric power used.

Data concerning pumping plants in Kern County.

Average depth to the water from the surface, in feet	10
Average suction 20 feet. Average total lift, in feet	30
Total yield of 25 plants, in second-feet	100.34
Total horsepower consumed	860
Total cost per day to develop 100.34 sec. feet, 860 H. P., at 15 cents	$129.00
Cost per second-foot for 24 hours	$1.29
Cost per acre-foot of water developed	$0.65

E. M. Roberts, of Bakersfield, has furnished the following data as to cost of operation on a privately owned steam plant, which has a particularly advantageous location:

Data concerning steam pumping plant at Bakersfield.

Equipment: 30 H. P. steam engine, No. 12 centrifugal pump, five 15-inch wells 40 feet deep; 6 feet to water, 15-foot suction, 21 feet total lift:

Cost of crude oil (fuel) and lubricant for 24 hours	$2.25
Cost of labor 24 hours	$4.00
Total cost	$6.25
Yield of plant	7 second-feet.
Cost per second-foot for 24 hours	$0.89
Cost per acre-foot of water developed	$0.45

Neither of these estimates makes any allowance for interest on investment in well and plant nor for deterioration, hence the costs as given are somewhat too low. It must be remembered, moreover, that Mr. Roberts's plant is in a particularly favorable situation, being close to the banks of the Kern, where the supply is regular and the lift slight. The standard of water costs in this district is set by the

price of gravity water from the Kern, 75 cents per second-foot for 24 hours, or about 38 cents per acre-foot, where distribution is affected by sales.

The pumped water therefore costs from 20 to 100 per cent more than the gravity water, and its cost will increase as it is developed from deeper strata with higher lifts. It seems to be quite generally believed locally that water at these prices can not be used profitably.

This may be true with the wasteful methods employed, the excessive amounts of water often applied, the class of crops produced, and the general lack of intensive cultivation; but it has been clearly proved in other communities and by individual experiences in the Bakersfield region itself that with more diversified or better selected crops, smaller individual holdings, and more intensive methods of farming, good profits may be made from the alkali-free lands of the delta and plains by the careful use of water at these or at even higher prices. It is safe to predict that the most important future developments in Kern County will result from the application of these principles.

Under any conditions that are likely to obtain in the near future it is not to be expected that ground waters at greater depths than 25 or 30 feet below the surface as an extreme will be usable for irrigation purposes. Water at this or less depth exists, of course, throughout the artesian areas along the lowest parts of the valley. It is to be found also throughout the greater part of the Kern delta and in the lower parts of the Poso Creek delta from a point about halfway between Famoso and Wasco westward. Near the foothills on each side of the valley, the ground water is not accessible except under unusual conditions, as in the flood plains of the larger rivers, or in areas where particularly valuable products, such as citrus fruits, will justify the expense of pumping to exceptional heights. In the intermediate areas between the deltas of the streams that supply the ground water, it is also apt to be too deep to be accessible. This condition is illustrated in the area between the Kern and Poso Creek deltas, east of Shafter station, on the Santa Fe railroad, and in the region between Delano and the foothills just south of the Tulare county line.

Near the northern edge of the county the main artesian belt of the valley, whose southern end is in the vicinity of Button Willow, expands to a width of 26 or 27 miles measured along the county line. Much of this central portion of the valley along the north edge of Kern County is in large holdings and is therefore but thinly settled, but developments are ample to prove the artesian conditions and to permit outlining the artesian belt with a fair degree of accuracy.

The outlines as determined are shown on the accompanying map (Pl. I), which also shows by means of hydrographic contours the depth to the ground-water level outside the artesian limits.

Although little direct evidence bearing upon this point exists, there can be no doubt that beneath the broad, steeply sloping west-side plains of Kern County the water is too poor in quality to be usable, except perhaps for stock, and that a few miles back from the trough of the valley it is too deep to be accessible. Generally, the water table beneath these west-side plains has but little slope, the depth to it at any point being approximately equal to the elevation of that point above the trough of the valley.

TULARE COUNTY.

GENERAL CONDITIONS.

Tulare County, lying north of Kern and east of Kings, includes the eastern edge of the large central artesian basin at its widest part, all of the delta of Kaweah and Tule rivers and a part of that of Kings River, and the famous citrus region of the foothills and the higher parts of the valley floor about Porterville, Exeter, and Lindsay. It also includes, in the southwestern corner, a part of the old bed of Tulare Lake and a part of the district submerged during the last extremely high water, in 1880. The high water of 1905–1907 did not quite reach the Tulare County line.

Kings, Kaweah, and Tulare rivers are the chief sources of such additions to the ground waters as are made in this county, as they are the sources of the surface waters used by the various canal systems.[a] Each of these streams has a distinct though rather flat delta, and the attitude of the ground-water plane indicates that the stream channels and canals along the crests of the deltas are the direct sources of the ground waters in the higher portion of the valley within Tulare County, and that from these lines of supply the waters percolate toward the lower parts of the valley and toward the areas between the deltas. These interareas receive only the slight direct supply from rainfall and from the minor streams that drain the foothills.

Within the artesian basin south and west of Tulare the ground waters, although receiving local additions within the county, are a part of the general body of ground waters of the central valley, stored there as a result of accumulation from all sources during centuries past, and are in general slow in motion northward along the valley axis.

[a] An account of these systems was published in Water-Supply Papers, U. S. Geol. Survey, Nos. 17 and 18. These papers are not now obtainable, but may be consulted in libraries.

FLOWING WELLS.

In the 365 or 370 square miles of artesian-water land within the county there were about 125 flowing wells in 1905, representing an investment of between $150,000 and $200,000. Nearly 100 of these wells were used for irrigation, and the combined yield of all of them was estimated at less than 25 second-feet. The greater number of them are 7 inches or more in diameter, while a few old wells are of smaller bore. They are most numerous on the Kaweah delta west of Tulare and somewhat farther south, west of Tipton and Pixley. Pasture lands, alfalfa, gardens, deciduous fruits, and vineyards are irrigated by the use of the waters developed.

PUMPING PLANTS.

Irrigation by the use of pumped water is more extensively practiced in Tulare County than anywhere else in the valley. This is due to the development of citrus culture along the foothills between Tulare River and Kaweah River, where methods in vogue in the citrus districts south of the Tehachapi have been introduced. There were in all about 170 pumping plants in use for irrigation in 1905 while a number of others were in use for domestic or town supplies. Of the total number, 125 were electrically driven and procured their power from one company; 45 were gas or steam plants.

These plants are adapted to a wide variety of conditions, some of them pumping from wells in which the water stands at the surface, and others lifting it from a depth of 100 feet. In the irrigation of some of the hillside citrus groves water is forced to heights of several hundred feet, usually from a reservoir into which it is pumped from the wells. The best equipped plants that overcome lifts of less than 75 or 80 feet use centrifugal pumps directly connected with motors; when the lifts are greater some form of deep-well plunger pump is used.

In the Lindsay district the ground-water level varies greatly each year, falling during the pumping season and rising again in the winter and spring. To keep the pumps and motors within the suction limit during the low-water period, and at the same time prevent their submersion during the winter season, some of the ranchers have adopted the plan of placing the machinery in a tank. In one plant examined, the motor and pump were fastened to a movable platform that could be raised or lowered in adjustment to the varying ground-water level.

The Badger Irrigation Company at Exeter has a particularly interesting plant because of the high lift of waters for irrigation purposes. There are three substations in the lowlands that deliver water to several citrus tracts at the base of the foothills, and to a

large reservoir. From this reservoir the water is forced on up the hill by a special design triple-plunger pump operated by a 75 horsepower motor. This pump has a capacity of 75 miner's inches from the 66-foot lateral to the 247-foot lateral; of 53 miner's inches from the 300-foot lateral to the 400-foot lateral; and of 36 miner's inches from the 530-foot lateral to the 586-foot lateral.

Difficulty was experienced when the plant was first installed because the pipe used was too light to resist the great pressure. At present three-eighths inch cast iron pipe of 6, 8, and 10 inch diameter is in successful use.

COST OF PUMPED WATER.

The charge made for power in this district by the Mount Whitney Power Company is $50 per year per horsepower for current used continuously, which equals 13.7 cents per horsepower for 24 hours; $30 per year per horsepower for current used in daylight only, which equals 8.8 cents per horsepower per day of 12 hours.

Estimates were made of the yield and cost of water from 50 plants using power on the first basis, with the following results:

Cost of water at fifty plants.

Average lift, in feet	79
Total yield of 50 plants, in second-feet	24.5
Total horsepower consumed	509.6
Total cost per day, 509.6 horsepower at 13.7 cents	$69.81
Cost per second-foot per day	$2.85
Cost per acre-foot	$1.43
Cost to lift 1 second-foot 1 foot for 24 hours	$0.036

Another estimate is given below of the cost of water from another group of 8 plants in the same district:

Cost of water at eight plants.

Average lift, in feet	30
Total yield, in second-feet	8.44
Total horsepower consumed	106.9
Total cost per day, 106.9 horsepower at 13.7 cents	$14.65
Cost per second-foot per day	$1.75
Cost per acre-foot	$0.88
Cost to lift 1 second-foot 1 foot for 24 hours	$0.058

These estimates indicate in a general way what irrigators are doing in this district under present conditions.

PERMANENCE OF THE GROUND-WATER SUPPLY.

Most artesian basins are very sensitive to development, old wells decreasing in yield as new ones are installed, the shallow wells and those about the upper, outer edge of the basin being the first to show signs of failure. Diminution in the flow of the less favorably

situated wells will take place in actual practice long before the basin is overtaxed, hence some alarm is likely to be felt and some individual loss may occur before alarm is justified by conditions. In addition to the normal diminution of flow in wells due to physical deterioration in casing or to other causes not related to a general loss of head and reduction in supply, a new well drilled in the neighborhood of an old one, or so situated as to draw in part from the same general zone of saturated porous materials, will affect the yield of the first, although the combined yields of the two are much greater than that of either alone and much less than the supply.

Until wells are withdrawing water from an area more rapidly than it is supplied, even though there may be reduction in the yield of individual wells, there is no cause for alarm. It is difficult to determine when this point is reached in an artesian basin because diminution in flowing wells begins soon after development has begun, but when waters are pumped it is less difficult to tell. The continued lowering of the ground-water level in a pumped well, through years of average or abundant rainfall with gradually increasing lifts and correspondingly increasing costs, indicates overuse.

A comparison of the flows of a number of artesian wells in Tulare County, measured first by the California State engineering department in 1885, and twenty years later by the United States Geological Survey, indicates, as is to be expected, a general diminution of yield, this decrease varying from 40 to 90 per cent. A part of it is undoubtedly due to the installation of new wells in recent years, but much of it is to be accounted for by the clogging and filling of the wells and the rusting of the casing. In any event the losses are not serious, and in view of the immensity of the basin and the large supplies that reach it annually, it can not be considered to have approached the point of overuse.

This observation, however, does not hold for some of the areas in which pumping is most intense. The lands favorable for citrus culture are distributed along a frost-free belt on the lower foothills and adjacent high parts of the valley floor. The zone of most intense pumping is along the eastern edge of the valley, between the deltas of Tulare and Kaweah rivers. The ground waters here receive some slight accessions from local run-off from the foothills and from minor streams that flow out from them, but their principal source is the constant supply that sinks in the deltas of the major streams and percolates thence slowly in all directions.

On the deltas themselves, especially along their lower portions, where so much damage has been done in recent years as a result of over-irrigation, the consequent rise of the ground-water plane and with it the alkali, pumping is most helpful; in fact, pumping will doubtless be one of the means by which the damage done by over-irrigation in the past will be remedied in the future; but in Tulare

County pumping thus far has been concentrated, upon those points remote from the deltas and from the trough of the valley, where supplies are least rapidly replenished. As a result there has been a noticeable lowering of the water plane in recent years and an increased cost of the water product. As a matter of safety to the orchards already producing, means should be taken to prevent the installation of additional pumping plants in those parts of the citrus belt where development is now most intense and the effects upon the ground water have been most clearly discerned, for it is obviously more important to protect the orchards that are already producing than to plant more.

KINGS COUNTY.

GENERAL CONDITIONS.

The valley portion of Kings County includes the present and past Tulare Lake bottoms and the southern slope of the lower Kings River delta. Tulare basin is the lowest point in the southern section of the valley and is the area in which all surplus waters from Kings River southward accumulate. The flood waters of Kings River are divided on its delta, part of them flowing northward to join the San Joaquin drainage, while the other part flows into Tulare Lake. During years of low or moderate snowfall and rainfall in the Sierra, practically all the flow of Kern, Tulare, Kaweah, and Kings rivers is used in irrigation, and there is but little excess to escape to the basin; but during years of heavy precipitation great volumes of water accumulate in the Tulare lowlands. This basin is very shallow. Its shores have gentle slopes, hence the area of the lake fluctuates widely, with slight changes in the depth of the water in it. Since settlement began in the San Joaquin Valley it has had a complex history. Grunsky has summarized what is known of its earlier history in Water-Supply Paper No. 17,[a] pp. 16 and 17. From his account that part of the following résumé which deals with conditions prior to 1897 is condensed:

Résumé of history of Tulare Lake.

1853.	High.
1853–1861.	Subsidence; elevation of surface in 1861, 204 feet.
1861–1863.	Rapid rise to highest known stage, 220 feet above sea level, overflowing into San Joaquin River; area about 800 square miles.
1863–1867.	Decline to about 208 or 209 feet above tide.
1867–1868.	Filled again to about 220 feet above tide.
1872–1876.	Fluctuated between 211 and 217 feet.
1876–1883.	Decline to 192 feet; lowest stage then known.
1883–1897.	Fluctuating; generally low.
1897–1905.	Decline; dry in autumn of 1905.
1905–1907.	Rise; elevation of water surface in summer of 1907, 193 feet; area of water surface summer of 1907, 300 square miles.

[a] This paper is not now available for distribution.

A knowledge of the history of this lake makes clear the origin and character of the soils of all except the northern part of Kings County, where the alluvial-fan or "delta" conditions so general in the San Joaquin valley prevail.

Evidences of the former occupancy of the lowlands by the lake appear everywhere. Faintly marked sandy beaches encircle the depression at various elevations and over these beaches are strewn the shells of the mollusks that lived in the lake. In its lowest parts, dry and planted in grain in 1905, the fine sediments that settled in the lake bottom make a fertile alluvial soil.

It is to be presumed that the history of the lake for many centuries has been like that part of it which we know directly, i. e., that it has fluctuated in area and depth, occasionally drying out completely, then filling to the point of overflow. Under such conditions relatively little of the water which it has contained can have escaped by surface overflow; the greater part of it has evaporated or has been absorbed by the sands and silts of the lake bottom.

With the shrinking of the lake during the years preceding the inflow of 1906, its old floor was placed under cultivation and valuable crops of grain were produced. This successful grain culture proves the nonalkaline character of the present surface of the old lake bottom, but the saline waters yielded by numerous shallow flowing wells within it indicate the presence of alkalies at slight depths. The few wells available as evidence in and about the borders of the old lake, however, indicate that the deeper wells obtain the better water.

Most of those that extend to depths of 1,000 feet or more develop waters sufficiently pure for irrigation or for drinking purposes.

FLOWING WELLS.

There are probably as yet less than 100 flowing wells in Kings County (77 were visited by Geological Survey representatives in 1905), yielding approximately 20 second-feet. Probably not more than one-third of the wells are used for irrigation, a large number of small-bore shallow wells being used for stock and for domestic purposes. The northern part of the county, in the vicinity of Hanford, Armona, and Lemoore, is well supplied with surface water by the canal systems that head in Kings River, and is a most productive, thoroughly cultivated area. Ground waters are not needed and no serious attempt has been made to utilize them here.

In the vicinity of Corcoran, Waukena, and Angiola, however, a successful colony has been established that depends almost entirely upon ground waters. A number of deep wells have been put down to depths of 900 to 1,600 feet, which yield flowing waters in amounts ranging from 5 to 40 miner's inches. Shallow wells have also been

bored and pumping plants have been installed over them. The tract includes about 30,000 acres, and alfalfa, cereals, sugar beets, dairy and garden products, and fruits are produced successfully.

FRESNO COUNTY.

GENERAL CONDITIONS.

Because of the fact that San Joaquin River forms the boundary that separates it from Madera County, Fresno County extends 25 or 30 miles farther north along the trough of the valley and along the west side than along the east slope. Thus the greater part of its lowland area is in arid west-side plains and in the relatively thinly settled central valley between Kings River at Lemoore and Laton and San Joaquin River at Mendota and Jameson.

Its best known, most densely populated, and most productive area is, of course, that about the city of Fresno, on the middle east-side plains, on the Kings River delta. This rich and populous region is irrigated by gravity water, distributed by a network of canals that take their supply from the river. These irrigation systems have been fully described by Grunsky.[a]

A later Water-Supply Paper, by Lippincott,[b] dealing with the possibility of storage and the development of water power on Kings River, embodies the results of a close study of the ground waters and their relation to alkaline conditions by Louis Mesmer and Thomas H. Means. From this report the following quotations are taken:

> The natural drainage of these lands is toward the southeast at the rate of about 6 feet to the mile. The soil is largely granitic sand, and below an average depth of 10 or 15 feet it is saturated with water. The surface water is somewhat alkaline and therefore it is not advisable to pump it for irrigation. Water below a depth of 50 feet can be considered satisfactory for irrigation. This is based on tests of more than 800 wells in the district, some of them being in sections where there were the strongest surface alkaline indications. In every case this lower water was found to be good, and when the strata near the surface are penetrated it rises to the elevation stated. There have been few attempts to pump water in larger quantity than is required for domestic purposes. A 2-inch screw pipe, put down to an average depth of 50 feet, landing the pipe on a stratum of clay, and then boring through the clay and allowing the water to come in from the bottom of the hole, is always ample for this purpose.
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> * * * * * * *
>
> A few small pumping plants have been installed—one 5 miles east of Fresno, on the Minnewawa ranch; several around Selma, and two near Wildflower—which yield at least 0.5 second-foot to a 7-inch unperforated well not more than 70 feet deep; with a lift not to exceed 20 feet in any case. Wells of 10-inch or 12-inch casing should be put down to a depth of about 100 feet on an average and should not be perforated above 50 feet below the surface, thus shutting off all possible chance of drawing from the more or less alkaline surface water. It is probable that wells of this size and depth would each furnish 1.5 second-feet. * * *

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[a] Water-Supply Paper, U. S. Geol. Survey, No. 18, p. 39 et seq. Out of print. May be consulted in libraries.

[b] Water-Supply Paper, U. S. Geol. Survey, No. 58. Out of print. May be consulted in libraries.

The result of pumping, * * * would be to improve the conditions rather than to increase the troubles from alkali. The water table would be lowered sufficiently to permit the washing down of the alkali salts, and the salts, instead of being confined to the surface layers of the soil, would gradually be distributed * * * and thus rendered harmless. The lowering of the water table would be of the greatest assistance in the reclamation of the lands already alkaline, and would probably permit this reclamation without extensive underdrains.

In a report by Lewis A. Hicks on the "Generation and transmission of electric power and installation of pumping plants," included in Water-Supply Paper No. 58, an estimate has been made of the cost of water pumped from the ground-water supply by electric power generated on Kings River. The estimates are made on the basis of 100 pumping stations, each with a maximum capacity of 5 second-feet and an average lift of 45 feet, and the probable cost of the water produced is given as 50 cents per acre-foot when the pumping plants operate 328½ days per year and $1.43 when the pumping plants operate 100 days per year.

Among the conclusions reached by Mr. Lippincott after a thorough investigation of conditions on the Kings River delta are the following:

(5) Pumping plants can be established and operated which will furnish 1,000 acre-feet of water every day at a cost not much greater than that now paid for gravity water from the canals, to supplement the present summer supply or to extend the irrigated areas.

(6) The operation of the pumping plants will partially, if not wholly, prevent the rising of alkali to the surface of irrigated lands.

The rise of the ground waters presents a difficult problem in practically all of the delta lands of the San Joaquin Valley, and is merely particularly well exemplified in the Kings River delta in Fresno County. Mr. Grunsky states that the rise in ground waters since the beginning of irrigation is from 10 to as much as 50 feet in parts of the delta. One great difficulty that arises in dealing with the problem is due to the fact that the injury is done in one locality while a large part of the cause may be in another. The lower part of the delta lands are the chief sufferers from the rise of the ground waters, but the cause is to be found in the irrigation on the higher lands as well as on those affected. Over portions of the central artesian basin and about its borders the ground waters have always stood close to the surface, and much of the land was alkaline before there was any settlement in the valley. The effect of the irrigation on the higher lands has been to extend this saturated and alkaline zone slowly up the slope toward the eastern margin of the valley. As a result of this extension it has encroached to a certain extent upon lands that were valuable.

Without storage the gravity waters will not serve an acreage greatly in excess of that supplied by them now, and the pumping plants that must be installed to secure future growth will in addition

serve a most valuable function in drainage, tending to prevent the extension of alkaline conditions and aiding in the reclamation of lands already alkaline.

FLOWING WELLS.

The flowing wells of the artesian belt of Fresno County are sparsely scattered over a broad area along the trough of the valley. There are only about 40 of them, all told, and they range in depth from less than 100 to 1,500 feet, the latter being the depth of one of the wells belonging to the Johns estate, north of Summit Lake. In the district adjacent to Lemoore, south of Kings River, small flows, sufficient for stock and domestic purposes, are obtained at 150 feet and less; but farther north no shallow wells are found.

Those on the James and Herminghause ranches, south of the San Joaquin River, are 600 to 800 feet deep. The flowing wells of the larger ranches were bored generally to obtain a supply of water for stock at times when none is available in the sloughs and irrigating ditches. Irrigation in these large holdings is as yet accomplished only during the flood season when abundant gravity water is available for lavish use. The possibility of using ground waters for such purposes is scarcely considered, although on one of the James ranches the water from a flowing well is used to irrigate about 50 acres of alfalfa.

The waters west of the San Joaquin River in Fresno County, whether within or without the flowing-well area, contain large proportions of salts in solution. This is a condition that is true of west-side waters everywhere within the valley, and apparently of all very deep waters near its northern end. South of Mendota, where the river no longer forms the eastern border of the county, the area within which waters of the east-side type appear extends 5 or 6 miles east of the valley axis. All of the waters of the upper east slope are very pure, but as they approach the lowest part of the valley they gradually assume the character of the waters there. In addition to the increase in the percentage of dissolved solids from the east toward the west across the valley, there seems likewise to be an increase from the south northward. The shallow flowing wells of Lemoore and vicinity contain very moderate amounts of salts in solution, while those in the vicinity of Mendota and Firebaugh and farther north carry from 1,000 to 20,000 or more parts per million.

The great west-side plains, with their productive soil, freedom from hardpan, good drainage, and favorable situation, are nonproductive because of their aridity, and must remain so until water can be applied to them. The ground waters beneath them are poor in quality and are deep. The ground-water plane seems to be nearly horizontal, such evidence as is at hand indicating a slope of only about 2 to 5 feet

per mile; hence it is nearly as far to ground water beneath any part of these plains as the plains themselves are above the lowest part of the valley. If experiments should prove that they will successfully produce citrus fruits or other high-priced products, then it may be that water can be pumped to them from the valley and the venture made commercially practicable despite the great expense involved, for it is to be remembered that water is pumped to heights of several hundred feet in Tulare and San Bernardino counties in localities where it can be used on good citrus lands with an excellent margin of profit.

At present the west slope is nearly without permanent residents. There are perhaps a dozen settlers between Panoche Creek and the Coalinga Branch of the Southern Pacific. Sheep camps, occupied temporarily in winter, are scattered over them. In the early nineties a few seasons of heavy rainfall led to settlement about Huron, and two or three crops of grain were harvested, but since then there has not been sufficient rainfall to mature a crop, and the plains have been abandoned to the sheep men who rent the grazing privileges from the large landholders, notably the Southern Pacific Railway Company, for 6 cents per acre per annum.

MADERA COUNTY.

GENERAL CONDITIONS.

The valley portion of Madera County is limited on the south and west by San Joaquin River and on the north by the Chowchilla. Irrigation by the use of surface water is practiced about Madera through the utilization of Fresno River waters in the early summer, when they are available, and about Minturn, near the north edge of the county, by the similar use of Chowchilla River waters. Both of these streams have small mountain drainage basins, so that the flow from them is not prolonged late into the summer.

The extreme western edge of the county is also under irrigation from gravity waters. The Chowchilla canal heads on the north side of the San Joaquin, about 6 miles east of Mendota, and runs northward, generally parallel to the river, for about 20 miles, commanding a strip 5 or 6 miles wide between it and the river. The greater part of the rest of the county is as yet grain land or pasture land, intensive cultivation being practiced only locally.

FLOWING WELLS.

The ground waters have not been drawn upon to any extent for irrigation in the developments that have taken place thus far. There are about 30 flowing wells in the 350 square miles of artesian water-bearing land in the county, and these are practically all used for watering stock on the Chowchilla ranch and the Miller and Lux

properties. The total yield for all of the flowing wells is estimated to be less than 8 cubic feet per second, although at least one of the individual wells yields more than 1 cubic foot per second. These wells are generally shallow, depths of 200 to 400 feet being usual. Some of them are among the oldest in California, having been drilled nearly forty years ago, and while there has been some lessening in yield it is undoubtedly due to deterioration of the casing and to clogging. A table of measurements made at different periods is appended:

Yield of flowing wells in Madera County.

Location.	Yield in miner's inches.		
	1871.	1884.	1905.
Sec. 21-10-14	20	13	10
Sec. 4-11-15	22	18	11
Sec. 25-10-15	4	6	.....
Sec. 16-10-14	1.1	3	12
Sec. 23-10-13	.....	5	2
Sec. 14-10-13	.....	23	12

The well in section 16-10-14 was recently cleaned and responded with a stronger flow than it had ever yielded before. The fact of a well-maintained pressure and supply is further indicated by the strong flows of new wells put down in the vicinity of older ones, tapping the same water bearing beds.

It is evident that these cheap waters can be developed in large volume in the western part of Madera County if it is desired.

PUMPING PLANTS.

About 15 pumping plants in the county are used for irrigation. Most of these are in the vicinity of Borden, where the ground-water level lies at a depth of from 10 to 20 feet. The pumps pull the water level down locally 15 or 20 feet, so that the total lift is usually 25 to 40 feet. Irrigators estimate that under these conditions they can deliver water for about 75 cents per acre-foot for fuel and labor. Even lower figures are given for the best equipped plants. The following estimates are recorded from the plant of A. L. Sayre:

Estimated cost of pumping water in Madera County.

Equipment, 60 horsepower gas engine, No. 10 centrifugal pump. Three 10 and 12 inch wells, 110 feet deep; depth to water, 16 feet; suction, 22 feet; total lift, 38 feet.

Cost of fuel per day of 24 hours	$5.47
Cost of labor per day of 24 hours	3.35
Total	8.82
Yield of plant, second-feet	6.23
Cost per second-foot for 24 hours	$1.41
Cost per acre-foot	$0.71

Interest on investment and deterioration of plant, of course, increase this cost somewhat; yet, it is certainly well within the limits of profitable use. Practically everywhere within that part of the county west of the Southern Pacific, except near the bluffs of San Joaquin River, pumping waters are accessible. As the foothills are approached, depth to ground water increases and the lift necessary in their development increases correspondingly.

MERCED COUNTY.

GENERAL CONDITIONS.

Merced County, unlike Madera County, extends entirely across the San Joaquin Valley and thus includes both east-side and west-side conditions. The gradual amelioration northward of the aridity of the south end of the San Joaquin Valley becomes noticeable at this latitude; hence, the raising of grain without irrigation, which is possible on the east side as far south as Fresno County, is usually successful on the west side in the northern part of Merced County.

Irrigation by surface waters is accomplished principally by the utilization of San Joaquin and Merced River waters. The lower line of the San Joaquin and Kings River canal, which leaves the river near Mendota in Fresno County, extends entirely across the west side of Merced County and into Stanislaus County. The high-line canal of the same system also extends from the southern to within a few miles of the northern edge of the county. This irrigation work commands much the larger portion of the west-side plain. The zone of unwatered land, between the high-line canal and the foothills, is relatively narrow.

The most important east-side system is the Crocker-Huffman canal, which taps Merced River about 2 miles below Merced Falls and serves an extensive section east and north of the county seat. The Stevenson-Mitchell canal heads in San Joaquin River about 14 miles southwest of Merced and commands a belt from 3 to 4 miles wide between this point and the mouth of Merced River. The principal settlement below this canal, the Stevenson colony, is between the lower Merced and the San Joaquin.

North of Merced River, the Turlock irrigation district extends into Merced County from Tuolumne County, in which lie the greater part of the lands covered by the system. In addition to these major systems, there are a number of minor canals along the Merced River bottoms. On the whole, however, the county is thinly settled and but a small portion of it is under irrigation. Perhaps three-fourths of the valley lands are devoted to dry farming, the production of hay and grain, or to pasturage.

The territory east and north of Merced, the Plainsburg and Le Grand districts in the southeastern part of the county, much of the foothill area, and the greater part of the strip on the north side of Merced River are producing hay and grain, while the greater part of the area between the Southern Pacific Railway (main line) and San Joaquin River is in pasture. Part of this pasture land was at one time tilled, but for various reasons, among them the rise of alkali, tillage has ceased, and the lands have been returned to pasture. On the west side the strip above the canals and between them and the hills is generally in grain from Dos Palos northward. South of Dos Palos this strip is utilized principally as sheep range.

FLOWING WELLS.

The use of ground waters, like surface irrigation, is more usual in Merced than in Madera County, although it has not as yet become extensive in either area. The total number of flowing wells in the county is between 125 and 150. The greater number of these wells are shallow, from 100 to 400 feet deep, and their yield is correspondingly small. As the most of them were drilled twenty or twenty-five years ago, not for irrigation but for domestic purposes and for stock, they fulfill the function for which they were intended. Of the 133 wells of which the Geological Survey has records, but 15 are reported as used for irrigation, and even these are generally used on a small alfalfa patch or garden of but little importance. The total yield of all the flowing wells in the county is estimated at less than 8 second-feet. That large yields may be secured is indicated by the experience of the Crocker-Huffman Company in sinking a 2,000-foot test well for oil in the spring of 1902 in sec. 15, T. 7 S., R. 13 E. No oil was found, but this well, although near the eastern edge of the flowing well area, as indicated by the shallow developments to date, yielded what is reported to have been the largest flow in the Merced district. When the casing was pulled the flow ceased, doubtless because of leakage into the upper strata. The water is said to have been soft and of fine quality.

By far the greater number of the flowing wells in the county are on the east side, south and west of Merced. The west-side developments are very meager. This is doubtless due in part to the fact that the San Joaquin and Kings River canal system supplies plenty of cheap gravity water to this district, but it is affected also by the fact that the west-side underground waters are of inferior quality. The flowing wells particularly, which must be deep, yield very bad waters. Some of them are too saline for irrigation. A few of the shallow wells near the main canals or the large laterals supply water sufficiently soft for any purpose. Most of the deeper waters along the axis of the

valley, as well as those along the west side, are alkaline. The experience of some of the irrigators in the Stevenson colony, who have found that the waters from certain flowing wells can not be used safely in the irrigation of fruit, proves this. In general, it may be said that the best ground waters are found well up the east slope, and that there is a progressive deterioration westward.

PUMPING PLANTS.

There are between 40 and 50 pumping plants in the county, most of them equipped with gas engines. More than half of these are used to develop irrigating waters, and the remainder are used chiefly for domestic or town supplies. Grain, fruit, alfalfa, berries, sweet potatoes, etc., are the principal crops raised by the ranchers, who use pumping plants for irrigation. They express themselves as satisfied with the results and convinced that pump irrigation in many parts of Merced County may be made highly successful.

In the Atwater and Livingston districts, as well as about Plainsburg and Le Grand, plants have already proved practicable. Throughout much of the east side, to the west, south, and east of Merced, the ground-water level is within 20 feet or less of the surface, and where soils are favorable, such accessible ground waters may be utilized to advantage in pumping operations.

Merced, like other east-side counties, includes a belt between the trough of the valley and the foothills that contains more or less alkali because of the proximity of the ground waters to the surface. In certain parts of this belt alkalinity has increased in recent years as the result of irrigation by means of gravity waters supplied by the Crocker-Huffman system. In such areas, if the lands are still productive, pumping, either as an independent source of irrigation water, or as an auxiliary to the gravity system, is most to be desired. It results in benefit to the community in several ways. In the first place, it is a method of drainage. The water that is supplied to the land is drawn from beneath it. The tendency of the ground waters to rise with irrigation is thereby counteracted and the ground water level is kept down. In the second place, there is no overuse. Each acre-foot of water developed costs a fixed sum. Under these conditions more will not be used than is needed and the usual tendency of the ground-water plane to rise with irrigation will not be manifest. Again, pumping and the use of relatively high-priced water encourages intensive cultivation and this again reduces the quantity of water necessary. Frequent cultivation and the creation thereby of a mulch at the surface has long been recognized as one of the effective means of prevention of loss of water by evaporation from the surface. Whether lands already damaged by alkali as a result of the applica-

tion of too much water can be reclaimed and utilized by pumping, under the economic conditions that now exist, is an unsettled question; but there is no doubt that the irrigation of undamaged lands whose water plane lies within 20 or 25 feet can be carried out successfully where intensive farming methods are used, and that the rise of alkalies in such lands will be prevented.

STANISLAUS COUNTY.

GENERAL CONDITIONS.

Stanislaus County, like Merced, extends entirely across San Joaquin Valley, and therefore both east-side and west-side conditions are represented within it. The valley in this latitude is contracted somewhat, so that its width is greater both to the north and to the south than here.

South of Tuolumne River and east of the San Joaquin, the canals of the Turlock irrigation district supply gravity water to a large part of the valley; and north of the Tuolumne the canals of the Modesto district supply the west-central part of the county from a point about 8 miles east of Modesto to San Joaquin River. West of the San Joaquin the lower line of the San Joaquin and Kings River canal system extends to the vicinity of Crows Landing. Under these canal systems much alfalfa is raised, dairying is an important and growing industry, and there is an increasing acreage devoted to fruit raising and diversified farming. Outside of the irrigated district the greater part of the valley lands are in grain, both wheat and barley being raised, although here, as in other parts of the Great Valley, the production is less than formerly. Along the San Joaquin the flooded bottoms and the neighboring alkali lands are used for grazing.

Less use is made of underground waters in this county than in any part of the valley. The rainfall is sufficient, so that grain raising has been successful in the past, and irrigation, therefore, has not been absolutely necessary in order that the valley lands might be utilized, and the pressure for irrigation therefore has not been as intense as in the more strictly arid sections farther south. Furthermore, the surface supply is more nearly adequate than in many of the counties, and the limits of productivity through the use of the cheap gravity waters have not been reached, because the Turlock and Modesto districts are not yet fully developed. The needs that result from a combination of such complete aridity that crop production is impossible without irrigation and full utilization of all surface waters that are available, are not as yet operative in Stanislaus County, and there has not yet been an influx of the type of settler who is content to develop small farm units intensively in the way that is resulting in such successful use of small pumping plants as prevails about Stockton and Lodi.

FLOWING WELLS.

The Survey has records of only 5 flowing wells in the county. These are near the southern boundary, and most of them are west of San Joaquin River. Only one, that on the McDermott estate, northeast of Newman, is used for irrigation. The others furnish supplies for stock. The water from all of these wells contains an excess of saline matter in solution, so that it must be used with care.

Because of the meager development, the limits of the area within which flowing waters are to be expected can not be determined with certainty. Nor are these limits of as much importance here as farther south in the valley, because the flowing wells will yield rather meagerly, their waters will be of poor quality generally, and the flowing-well area will be confined to a zone of low land along the axis of the valley, much of which is subject to overflow and some of which is alkaline.

The settlers along the west side—owners of fertile, alkali-free soils, capable of immense production if water could be applied to them, but practically limited under present conditions to dry crops—are as a matter of course deeply interested in the possibility of securing irrigation water from any source. The streams that flow from the west-side hills toward the valley are wet-weather streams of slight flow and can not be considered as sources of irrigation water.

The San Joaquin and Kings River canal system may be capable of slight extension when irrigation practice on the lands under it improves; but at best it can serve only a small additional acreage. It is probable that pumping systems will eventually be installed to lift water directly from the San Joaquin to apply to those west-side lands that are within 40 or 50 feet of the low-water level in the river. Pumping plants may also be installed in the lower west-side lands to pump ground waters, but the lift will be nearly as great as from the river and the water will be of inferior quality, since all of the west-side ground waters contain notable quantities of salts and some of them approach the limit of usability for irrigation.

PUMPING PLANTS.

Pumping plants for irrigation are practically unknown in this county, but one or two being in operation. They are used, however, to supply the stations of the Pacific Coast Oil Company, the railroads, and the domestic supply for the city of Modesto. Ground waters are accessible with moderate lifts throughout the west half of the east slope of the valley, and as irrigation progresses under the gravity systems and the water plane rises, it will become increasingly desirable as a means of drainage as well as a source of auxiliary or independent gravity waters. That intensive cultivation and careful methods will make it as practicable here as it is elsewhere in the valley, scarcely needs affirmation.

SAN JOAQUIN COUNTY.

GENERAL CONDITIONS.

San Joaquin County is, with the exception of small areas in Alameda and Contra Costa, the northernmost of those counties whose valley lands belong to the southern division of the great central lowland of California. Because of its latitude and its position near the gateway that opens to the Pacific, it differs greatly climatically from the southern counties of the valley. Its temperatures are not as high and do not fluctuate through as wide a range (monthly averages vary from 46.5° in January to 72.5° in July and August), its rainfall is greater, amounting to about 15.5 inches, and its percentage of foggy days exceeds that of Kern, Tulare, and other of the southern counties. Furthermore, situated as it is along the lower San Joaquin, it includes a tidal section of that stream and a large area that is subject to inundation when the Sacramento is in flood, and a still larger section subject to overflow when floods in the San Joaquin and its tributaries occur at the same time as those of the Sacramento. The county, therefore, includes a part of that Central California area, whose problems of reclamation, drainage, and navigation involve in so complete and fascinating a way all of the phases of hydraulic engineering. The rivers must be improved and controlled for navigation purposes, the lowlands must be protected from floods and drained, while the higher bordering parts of the valley lands, too dry to produce the more valuable crops although suited to grain raising, require irrigation for their fullest development. This threefold problem belongs typically to the Sacramento Valley, but it requires solution also in that of the lower San Joaquin.

The Stanislaus Water Company takes its supply of water from the Stanislaus near Knights Ferry and irrigates an area of several thousand acres along the southern border of the county in the Escalon and Manteca districts. In the Lodi and Stockton districts the systems of the Stockton and Mokelumne Irrigating Company and the Woodbridge Canal and Irrigation Company supply surface waters to limited areas. Within the island district, west and north of Stockton, where reclamation has been accomplished by the construction of protective levees, water is sometimes admitted within the dikes during high-water periods in the streams for irrigation purposes, but as subirrigation is effectual throughout the greater part of these areas, surface irrigation is rarely necessary. The higher lands of the valley slopes, both along the east and west sides, are devoted to grain raising, as some of them have been for almost half a century. No water is applied to them. There is no uniformity as to practice among the vineyardists, some of them irrigating their vines, others preferring that they be not irrigated.

FLOWING WELLS.

San Joaquin County includes the northern portion of the great central artesian zone of the valley, but as this zone is less important in its northern part, both because of the inferior yield of wells there and because of the greater proportion of water of poor quality obtained from them, there has been relatively little development for irrigation purposes or domestic supply. Twenty-nine records have been obtained and these are believed to include all of the flowing wells in the country districts and nearly all of those in the city of Stockton. Only six of these supply water that is suitable for irrigating purposes and the yield of these is small. By far the greater number of the flowing wells have been drilled for the gas they yield. In all such wells, the water with which the gas occurs is saline and is allowed to waste, since it is not usable for drinking purposes or for irrigation.

The few artesian wells that furnish water of good quality not only yield small supplies but are expensive because of their considerable depth. Those of which records are available are from 975 to 1,200 feet deep. Wells of lesser depths do not yield flows, and those with greater depths, at least in the Stockton neighborhood, yield saline waters and gas. Farther west than Stockton, nearer the axis of the valley, it is probable that the water, even from shallow wells, would be alkaline. It will be realized that under these conditions flowing wells are not of value for irrigation purposes in the county, despite the rather large area over which flows may be obtained.

PUMPING PLANTS.

During the last few years irrigation by the use of pumped waters has become an important factor in the development of the east side of San Joaquin County. Around Lathrop and French Colony, in the district east of Stockton and in the country about Lodi, a large number of plants have been installed and new wells are being sunk and new plants put in operation constantly.

This development is of a most promising type. Most of the plants are small and the acreage irrigated by each is limited. This means small holdings, intensive cultivation, and eventually relatively dense settlement. The average recorded horsepower of 193 plants is only 6.2. Of the 193 plants 138 develop from 2 to 8 horsepower, while 42 are equipped with engines developing from 10 to 15 horsepower. One hundred and eighty-seven gas engines are in use, thirteen plants use motors, and two are operated by steam.

One hundred and thirty-seven owners of plants report a total of 1,455 acres, an average of only 10.6 acres each. The cost of 106 of

the plants is reported by the owners as $64,983, an average cost of $613 each. These facts indicate the small scale and individualistic character of the development.

The power companies charge a uniform rate of 3⅓ cents per horsepower per hour. This is higher than the fuel charge in the gas plants, the reported average in 12 plants for the summer of 1906 being 1.45 cents per horsepower per hour, but labor and installation, both of which are heavier charges in the gas plants, tend to equalize the difference. Water as developed in these small plants seems to cost the users from $1.50 to as much as $3 or $4 per acre-foot.

Generally water is delivered from the pumping plants to the acreage served through earth ditches, and where the soil is sandy and porous this method results in much waste.

The pumping-plant wells are comparatively shallow, and hence are very much cheaper than the deep wells necessary to secure artesian flows. The average depth of somewhat more than 100 wells, taken at random from the records, is about 80 feet. Another group of 20 wells average only 40 feet in depth. These latter wells are equipped with small pumping plants, developing an average of 5 horsepower each, and the water which they yield is ample.

The wells are particularly cheap because it has been found that in many parts of the area it is not necessary to case them, or at least they must be cased only to slight depths. Twelve pumping-plant wells are reported as without any casing; 24 others were only partially cased, the pipe in these varying in length from a few joints to three-fourths or seven-eighths of the entire depth of the well.

The windmill has been an important factor in the past in irrigation in the Stockton district, and although it is being rapidly superseded by the small pumping plant, it is still extensively used, especially in the vegetable garden and fruit districts east and northeast of Stockton. Its chief disadvantage, of course, is the uncertainty of the wind. It is not unusual to see a well equipped both with a small gas engine and a large windmill, the engine being used when the wind fails. The wheels used are of wood and of local manufacture, from 18 to 22 feet in diameter, and cost complete with the tower from $175 to $200.

Much of the gardening and fruit for the San Francisco market is in the hands of Italian immigrants, who, after giving the windmill a thorough trial, are now abandoning it in favor of the more reliable small gas engine.

Irrigation by pumping, of the general type practiced about Stockton and Lodi, could be extended with great advantage throughout a large acreage, now without water, between the Mokelumne and Tejon Pass, but to be practiced successfully it will require a different spirit from that which as yet largely dominates the West. The promoting

and speculative spirit, the desire to get rich overnight, to control large holdings, and to avoid personal labor, will have to be superseded by a willingness to be satisfied with sure but moderate returns, to be content with small farm units, and to attain personal independence through individual effort. It is to be hoped that the American citizen of the generations to come will prove willing to accept these conditions and that in the future dependence need not be placed upon our adopted citizens for detailed development of this desirable type.

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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

WATER-SUPPLY PAPER 223

UNDERGROUND WATERS OF SOUTHERN MAINE

BY

FREDERICK G. CLAPP

WITH

RECORDS OF DEEP WELLS

BY

W. S. BAYLEY

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UNDERGROUND WATERS OF SOUTHERN MAINE.

By Frederick G. Clapp.

INTRODUCTION.

LOCATION AND AREA.

The area covered by this report is roughly triangular and includes all of southern Maine, from the coast northward beyond Calais, Oldtown, Skowhegan, and Rangeley. Its northern boundary may be said to follow very nearly the line of the forty-fifth parallel, but a few towns situated a short distance north of the line have, for special reasons, been included in the discussion. Fig. 1 shows the relation of this area to the rest of the State. Its greatest extent east and west is 210 miles, and north and south, along the New Hampshire line, about 130 miles.

CHARACTER OF REPORT.

It was originally intended that the entire State should be covered by a single report, but field investigations showed that the subject was much broader than at first supposed. Although there are large areas which are settled either sparsely or not at all, where little information regarding underground waters can be obtained and little is yet needed, there are wide areas where the water problem is very important and extensive well drilling is going on. This is true of the summer-resort regions, and of the great farming region covering the larger part of Aroostook County. It was found impracticable, therefore, to include the entire State in a single report, and it was decided to confine this report to the region south of the forty-fifth parallel, and to cover the northern part of the State by a special investigation.[a]

In order to meet the needs of all classes of readers the report is so subdivided as first to describe the general water resources of the region, the dependence of quality and quantity on character of rocks,

[a] The report for the northern part of the State is in preparation.

the location and type of wells, etc., and then to discuss in detail the conditions in the various counties, for the benefit of persons needing

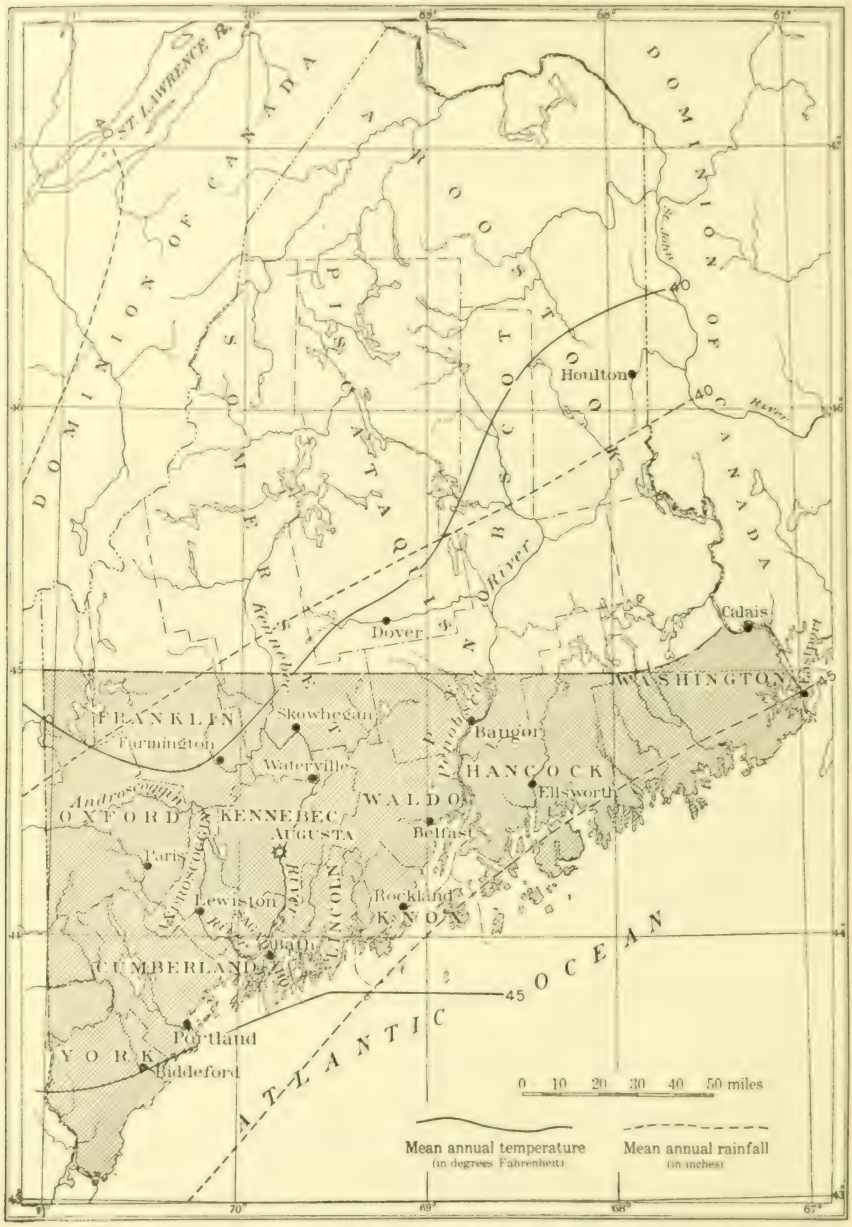

FIG. 1.—Index map showing area described in this report; also mean annual temperature and mean annual rainfall for Maine.

local information. The table of deep wells, compiled by Professor Bayley, is appended for the benefit of persons desiring to drill wells.

NEED OF INVESTIGATION.

The available knowledge regarding the underground-water resources of Maine has heretofore been rather scant. Surface waters and open wells have been largely used, and where deep wells have been resorted to they have been drilled at random, without a scientific forecast of the amount or the quality of the water available at that particular point or with that particular type of well. People are now beginning to realize that well drilling, like other prospecting, in order to be economical to the owners and drillers, must be conducted in accordance with certain scientific rules, which point out the source, depth, amount, and quality of water in different types of rock and different localities. Hence a comprehensive investigation is necessary throughout the State.

The Geological Survey frequently gets requests for information regarding the occurrence or the quality of water in certain towns. In sections of the State where water is scarce, as on the islands and along the coast, especially in the summer-resort region, it is necessary that people should be informed whether it is possible to obtain water by drilling, and if so, at what depth it may be procured. Many towns in the State are searching for a public supply, and some towns have poor supplies and wish to improve them. This report aims to help in solving such problems. Another object in view is the securing of proper well construction. In some parts of the State and by some drillers the most modern methods of drilling and casing wells are used; elsewhere, however, and by other drillers, wells are improperly constructed and some are dangerous to the public health. A comparison of the various methods of construction ought to teach valuable lessons.

SOURCES OF INFORMATION.

Previous literature.—The first lists of deep wells and springs in Maine were published in 1904.[a] A few additional wells were recorded in 1905.[b] A brief account of the underground-water conditions, with lists of important springs, was also given in 1905,[c] and in the same year the conditions in the Kittery-York district, in the extreme southwest corner of the State, were described.[d] A short paper in the same report described a possible water supply from glacial gravels in the vicinity of Augusta.[e]

Correspondence.—Much of the data contained in the first three of the above-mentioned reports was gathered by correspondence, but whenever records could subsequently be obtained in the field they

[a] Bayley, W. S., Water-Supply Paper U. S. Geol. Survey No. 102, pp. 27–47.
[b] Darton N. H., Water-Supply Paper U. S. Geol. Survey No. 149, p. 63.
[c] Bayley, W. S., Water-Supply Paper U. S. Geol. Survey No. 114, pp. 41–56.
[d] Smith, G. O., Water-Supply Paper U. S. Geol. Survey No. 145, pp. 120–128.
[e] Smith, G. O., op. cit., pp. 156–160.

were added to the list. In obtaining records blanks were sent out containing questions to be answered by well owners or drillers. Considerable information regarding mineral springs has also been obtained by correspondence since the field work was finished.

Field work.—The field work for the present report was done during four months in the summer of 1906. The author was assisted by George C. Matson and B. L. Johnson, and many of the data here given are taken from their notes. It was impossible to visit every town, but all the larger places and those localities which present special problems were visited, and the conditions of occurrence and the quality of well and spring waters were investigated. All public water supplies from underground sources were seen, the important mineral springs were visited, and interviews were held with professional well drillers in order to get authoritative information regarding conditions of drilling.

ACKNOWLEDGMENTS.

The accuracy and completeness of this report have necessarily been dependent to a considerable extent upon the work of other persons besides the author. George C. Matson and B. L. Johnson have assisted in both field and office work. A number of years ago Prof. W. S. Bayley was requested to prepare a table of deep-well records of Maine, which were obtained by correspondence extending over a considerable period of time. These records as submitted by Professor Bayley contained some additional descriptive matter, which has been added to this report. The table has been revised and brought up to September, 1906, and appears on pages 242–259. Several pages of the report, bearing on occurrence and methods of obtaining water in general, have been compiled from notes furnished by M. L. Fuller. Some of the geologic descriptions are taken from reports by George Otis Smith and E. S. Bastin. A large number of the chemical analyses were made by Prof. F. C. Robinson, the samples being collected by A. C. Robinson. Analyses made by other chemists which were not originally expressed according to the uniform system adopted by the United States Geological Survey for use in its publications were submitted to R. B. Dole, of the Survey, for recomputation. C. E. Shute, C. H. Scribner, Fred Foster, Lester Maxwell, and the Poland Brothers, all prominent well drillers, have taken an interest in the investigation and furnished much valuable information. Other drillers have assisted in gathering data.

A comprehensive report on water supplies is manifestly impossible without the assistance of persons in the region which is to be benefited by the report, and in compiling the facts here presented it has been necessary to interview hundreds of residents of the State and to

correspond with several hundred more. To all who have assisted, directly or indirectly, the author wishes to express his thanks. In furnishing information to the Survey they have performed a valuable public service.

RESULTS OF INVESTIGATION.

The investigations thus far conducted in Maine have shown that there is an abundance of water beneath the surface in granite, slate, and other rocks, but as the water occurs in crevices which are not regularly distributed through the rocks, the amount which will be found at any given location or depth is uncertain and can never be definitely predicted. Water in the rocks is usually of good quality, but in some districts it has a large mineral content. Water in surface deposits is generally abundant except in dry weather, but the quality can not be depended upon. It has been found that drilled wells are the most satisfactory and that dug wells and combinations of dug and drilled wells are to be avoided, especially in villages. Most of the commercial mineral springs of the State are safely situated, and their water is of excellent quality. Only a few springs were seen which should be condemned. The public water supplies are mostly satisfactory, but in a few of them, owned by private parties or corporations, the water is badly polluted. In such cases the abandonment of present sources is recommended. No special investigation of surface supplies was made, but it is known that some of these are not satisfactory and that changes should be made.

SETTLEMENT AND DEVELOPMENT AS RELATED TO WATER UTILIZATION.

With the exception of Florida, Maine is the least densely populated of all the Eastern States (23.2 per square mile). Because of this fact and the abundance of lakes and streams, its people have until recently felt little necessity for seeking sources of water supply below the surface. Consequently the underground waters of the State have been, on the whole, but slightly utilized, except in certain restricted areas, where for one reason or another the surface waters have not been suitable for domestic or manufacturing purposes.

Until very recently the rivers and lakes have afforded excellent water for nearly all purposes. With the increase in the number of factories established on the main waterways the rivers have become less and less valuable as sources of water supply, partly because of the waste products poured into them from the factories and partly because of the increased amount of sewage which they must carry in consequence of the growth of the manufacturing communities on their banks.

The drift of the population toward centers is well shown by the census of 1900. The number of cities and villages separately enumerated in this year was 43, as against 25 in 1890, and their population was 258,431, as against 184,821 in 1890, or 37.2 per cent of the total population in 1900, as against 28 per cent in 1890.

The natural result of the two tendencies above mentioned has been pollution of the principal watercourses, with the consequence that communities drawing their public supplies from streams are beginning to complain of the quality of the water furnished them and are turning toward lakes or wells for relief.

Along the coast, where the larger rivers are tidal, communities are dependent on lakes and small brooks for their public supplies. On the islands the principal sources of drinkable water are springs and drilled wells, but as there are only a few island settlements of any considerable size the question of large public supplies for the islands is not of great moment. The rapid growth of summer-resort communities has brought about a demand for information regarding deep-well prospects in such places. In the interior of the State many villages that are not situated near large lakes or spring-fed brooks have taken advantage of the good springs and have obtained through pipes a supply of spring water.

SURFACE FEATURES.

GENERAL STATEMENT.

Water is found in some amount in all formations below the earth's surface from the loosest and most porous sands and gravels to the hardest slate and granite. The amount varies from the merest trace chemically combined in the molecules of the rocks to immense reservoirs which supply wells flowing hundreds of gallons per minute. Some waters are so pure that a refined chemical analysis shows only minute traces of organic and mineral matter; others are so heavily charged with minerals or other impurities as to be unsuitable for use.

The slope of the surface at any point is one factor determining the amount of water absorbed by the ground. The direction and amount of slope also determine the form of the water table—that is, of the upper limit of saturation. Except where the surface is flat the water table is generally not parallel with the surface; it is almost invariably farthest from the surface on the summits of hills and mountains and nearest to it in valleys and along the coast, reaching the surface in swamps and along rivers, lakes, and beaches. The surface of the water table is always in motion, its higher portions flowing toward the lowest outlets along rivers or the sea. This direction of flow explains why fresh water is usually found when a well is dug in a sandy beach.

PRINCIPAL SURFACE FEATURES OF SOUTHERN MAINE.

Altitudes in Maine range from sea level to about 5,200 feet, the highest summit being Mount Katahdin. In some of the central portions of the State the land is very mountainous, but in parts of Aroostook County it is nearly flat. The surface may be said to consist essentially of an extensive southward-facing slope draining directly into the Atlantic Ocean and a smaller northward-facing slope draining into St. John River. The latter area is a great plain with numerous swamps, above which rise a few hills. The surface of the southern slope is much more broken. Its western portion is crossed by ridges of low mountains trending east or northeast, some of which rise several thousand feet above the surrounding country. These are separated by wide areas of plain, on which are many small hills and ridges. Near the coast much of the surface is rough. Rocky ridges and low, bare hills stretch from the shore line some miles inland, but few of these hills are lofty and the valleys between them are not deep. The coast is in most places rocky, but at some points there are sandy beaches, several of which are among the finest in the country.

DRAINAGE.

GENERAL DESCRIPTION.

No other tract of country of the same extent on the continent is so well watered as Maine. The State contains five principal lake systems—that is, large lakes connected by rivers and discharging into main channels which convey their accumulated waters to the ocean.

These systems are, beginning on the western boundary, (1) the Umbagog-Rangeley series, with an area of 90 or more square miles, drained by Androscoggin River; (2) the Moosehead series, forming the headwaters of Kennebec River, the main lake of which is 120 square miles in area and is the largest inland body of water in New England; (3) the Penobscot series, consisting of Chesuncook and its surronding lakes on the West Branch of the Penobscot; Alleguash, Chamberlain, and others on the East Branch, and the Seboeis and others connected with it still farther east but flowing into the East Branch of the Penobscot; (4) the Schoodic Lakes, in the southeastern part of the State, drained by St. Croix River; and (5) the many lakes forming the headwaters of St. John River and its tributaries. There are many other lakes in every county, which, though of small area, in the aggregate hold an immense amount of storage water and add much to the importance of the lake systems of the State. The total number of lakes, not including small ponds tributary to the rivers, is 1,620, and their total area 2,300 square miles, making one lake to each 20 square miles of territory and one square mile of lake surface to each 14.3 square miles of land surface.[a]

DETAILED DESCRIPTIONS.

The main drainage systems within the area covered by this report are described below, the descriptions being taken from the paper by Pressey just cited.

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[a] Pressey, H. A., Water powers of the State of Maine: Water-Supply Paper U. S. Geol. Survey No. 69, 1902, p. 16.

Saco River system.—Saco River rises in the White Mountain region of New Hampshire at an elevation of about 1,900 feet above the sea, and has a general southeasterly course to the Atlantic Ocean. The greatest length of the basin from Mount Washington to the sea is about 75 miles; the greatest width about 30 miles. The total drainage area is 1,750 square miles, about equally divided between Maine and New Hampshire. The general elevation of the basin is greater than that of any of the larger streams of Maine except the Androscoggin. The headwaters are in one of the highest and roughest mountain regions in the eastern part of the United States, with steep, wooded slopes and narrow river valleys and with heavy falls to the mountain streams. The mountains grow gradually lower, however, as the ocean is approached, becoming undulating hills in the central part of the basin and comparatively flat land near the sea. The northern part of the basin is still largely wooded, while in the southern part practically all of the forests have been cut, so that more than half the entire basin has been cleared.

Presumpscot River system.—This is one of the most interesting as well as one of the best water-power streams of its size in the United States. It is the outlet of Sebago Lake, which lies about 17 miles northwest of Portland. The lake is fed by Crooked River, a stream heading 35 miles farther north and within 3 miles of the Androscoggin. The area of the lake is 50 square miles, the area of its drainage basin at the outlet of the lake is 470 square miles, and the total drainage area of the river at its mouth is 700 square miles. The northern part of the basin is mountainous and wooded, while the southern part is moderately hilly and cleared of trees.

Androscoggin River system.—The Androscoggin River is formed by the junction of Magalloway River and the outlet of the Umbagog-Rangeley lakes near the Maine-New Hampshire boundary line. For about 35 miles it flows southward into the State of New Hampshire, then turns abruptly to the east and flows into the State of Maine, then turns to the south and joins the Kennebec in Merrymeeting Bay. The total drainage area above Brunswick, where is the last fall, is 3,700 square miles, about 80 per cent of which is in Maine. The greatest length of the basin is 110 miles, the greatest width 70 miles, while the river itself measures about 200 miles in length from the sources of Magalloway River to the coast. * * * The lower part of the basin is hilly and moderately wooded, while the upper two-thirds is very broken and mountainous and heavily timbered.

Kennebec River system.—The Kennebec River basin lies between those of the Androscoggin and the Penobscot, and extends from the Canada line to the ocean. The basin measures 150 miles in length and varies in width from 50 to 80 miles in the main portion, embracing a total area of 6,330 square miles. Of this area 1,250 square miles are tributary to Moosehead Lake. The general elevation is less than that of the Androscoggin basin, though near the center of the area Saddleback, Abraham, and Bigelow mountains rise as isolated peaks to elevations higher than any [other] mountains in the State except Katahdin. The river rises in Moosehead Lake, though its headwaters are collected by * * * a number of small streams rising in the hilly forested areas lying to the east and west of that lake. Near Moosehead the hills and highlands are well back from the lake, leaving a great open plain. The northern part of the drainage basin is broken by offsets from the White Mountains. Nearly the whole of the upper portion of the drainage area is forest covered and in its original wild state.

Penobscot River system.—The Penobscot has the largest drainage basin of all the rivers in Maine, comprising about 8,500 square miles, or more than one-quarter of the entire State. Its greatest length from north to south is 160 miles, its greatest width 115 miles, all within the State. Eight hundred square miles of the basin discharge their waters into the main river below its lowest water power at Bangor. The basin is at a lower elevation above the sea than the basins of the Kennebec and the Androscoggin, as would be expected from the general southeasterly slope of the country toward

the Atlantic Ocean. The northern portion, however, is rather elevated, having a mean height of about 1,000 feet. The highest portion of the basin is at the headwaters of the main river, where the elevation is from 1,600 to 2,000 feet. Taken as a whole, the basin is rather uniform in its topographic features. Hills and low mountains stretch from near the sea above Bangor; farther north is an undulating plain, while to the west the surface becomes more broken and greatly diversified by hills, detached peaks, lakes, ponds, and swamps. At the south the basin merges into that of Kennebec, and at the north into that of the Alleguash. * * * A large part of the basin is what is known as "wild land," being heavily timbered and known only to the lumberman and the sportsman.

St. Croix River system.—St. Croix River is formed by two branches, known as the Upper St. Croix or Chiputneticook River, the outlet of the Schoodic Lakes, and Kennebasis River, the outlet of the western lakes of the area, known as the Kennebasis Lakes. The Upper St. Croix, with its tributary lakes, forms nearly half of the eastern boundary of Maine, separating that State from New Brunswick. The total drainage area of the main stream is about 1,630 square miles, of which 960 square miles are tributary to the great reservoir systems controlled by dams at Vanceboro and Princeton. The length of the stream from the headwaters to the mouth is 100 miles. The basin is, in general, lower than that of any of the larger streams of the State flowing into the Atlantic, its headwaters having an elevation of about 540 feet. * * * The lake system of the St. Croix is the largest in the State in proportion to the drainage basin, except that of the Presumpscot. * * * The lake system of the Upper St. Croix comprises approximately 50 square miles of lake surface, and that of the West Branch 70 square miles, considering only the principal lakes and ponds. Indeed, above Vanceboro and Princeton each branch of the river is simply a succession of lakes to almost the extreme headwaters. The total lake surface of the St. Croix is estimated as not less than 150 square miles, or nearly one-tenth of the total drainage area.

Coastal streams.—Between the St. Croix and the Penobscot are Dennys, East Machias, West Machias, Narraguagus, Union, and other rivers, and between the Penobscot and the Kennebec are the St. George, the Pemaquan, and others, while at the southwestern extremity are the Mousam and the Piscataqua, the latter forming a part of the western boundary of the State. These streams are all comparatively small, but their importance is greater than their size would indicate, from the fact that they are in a more thickly populated part of the State and are nearer the coast, where transportation facilities are much better than in the interior, and that they have considerable fall and regular flow, due to the lakes and ponds tributary to them.

RELATION OF CLIMATE TO UNDERGROUND-WATER CONDITIONS.

The climate of Maine is healthful. Although the winters are long and severe the summers are pleasant and warm. The mean annual temperature ranges from 37° at Fort Kent to 46° at Portland.[a]

The mean annual precipitation ranges from 35.3 inches at Fairfield to 52 inches at Mayfield, Somerset County, there being 11 climatological stations in the State, as shown by the accompanying table. Fig. 1 shows the isothermal and isobaric lines for the State.

[a] Boardman, S. L., Special Rept. U. S. Dept. Agr. No. 4 1884, pp. 16–20. Henry, A. J., Bull. Q, U. S. Weather Bur., 1906, pp. 122–134.

Climate and rainfall statistics at stations in southern Maine.[a]

	Fairfield.	Mayfield.	Orono.	Rumford Falls.	Eastport.	North Bridgton.	Lewiston.	Gardiner.	Bar Harbor.	Corinna.	Portland.
PRECIPITATION.											
Spring.....inches.	8.4	12.2	10.1	10.8	11.3	12.9	11.6	11.5	12.2	11.4	10.6
Summer.....do..	9.1	16.8	10.2	11.5	10.0	11.8	10.6	9.4	9.3	12.6	10.2
Autumn.....do....	8.9	11.8	10.4	9.7	11.1	11.2	11.5	10.4	12.9	12.2	11.0
Winter.....do....	8.9	11.2	11.9	10.1	11.0	11.7	12.5	11.7	14.5	11.7	11.0
Annual.....do....	35.3	52.0	42.6	42.1	43.4	47.6	46.2	43.0	48.9	47.9	42.8
TEMPERATURE.											
Maximum.....degrees F..	97	96	100	101	93	100	100	101	96	97	97
Mean maximum.....do....	53	54	53	52	49	55	54	56	53	52	53
Minimum.....do....	−37	−22	−36	−29	−21	−26	−24	−30	−17	−19	−17
Mean minimum.....do....	32	32	33	33	35	34	34	35	35	37	38
Mean annual.....do....	43	42	43	43	42	44	44	45	44	44	46
Average number of days over 90°.....	2	2	2	3	1	3	5	8	1	3	3
Average number of days under 32°.....	172	168	156	151	133	153	150	152	151	140	127
FROST (AVERAGE).											
Latest killing frost in spring.....	May 13	May 17	May 11	May 15	Apr. 28	May 15	May 5	May 6	May 18	May 23	Apr. 14
Earliest killing frost in autumn.....	Sept. 24	Sept. 22	Sept. 24	Sept. 20	Oct. 12	Sept. 15	Oct. 2	Oct. 1	Oct. 12	Sept. 12	Oct. 18

[a] Henry, A. J., Bull. Q., U. S. Weather Bureau, 1906, p. 714.

As a rule, the rainfall is fairly well distributed throughout the year, some of it occurring in every season. Thus a large part of the precipitation occurs when the ground is unfrozen, and much of the rain penetrates the ground and goes to increase the underground water supply.

The winters often begin in November, but the climax of the season is not reached till February, and the winter generally ends in April. The summers are, as a rule, short, generally beginning abruptly in June. Fair weather predominates. In July and August there are frequently several successive days of muggy weather, followed by cooler spells, generally with east winds, during which the contrast in temperature is striking. The coldest place in winter is Fort Kent, and the coolest place in summer is probably Eastport, which has a summer mean temperature of 59°. Summer generally terminates gradually in the latter part of September.

UNDERGROUND WATERS.

SOURCE OF UNDERGROUND WATERS.

Rainfall.—Practically all the water utilized for domestic purposes is supplied by rain. The 35 to 52 inches of rainfall disappears from the surface principally in three ways—(1) by evaporation; (2) by run-off through the streams; and (3) by absorption into the rocks and unconsolidated deposits. It is with the last-mentioned portion of the rainfall that an underground-water report is concerned.

Evaporation.—Evaporation, although far less conspicuous than the other methods of removal of the water from the surface, is nevertheless one of the most important. The quantity thus removed commonly amounts to one-half or more of the total water falling as rain. This water never enters the ground, and therefore does not become a source of supply for domestic or other purposes.

Run-off.—The run-off includes the water that flows over the surface into streams and lakes and is carried seaward through definite channels. The quantity disposed of in this way is dependent partly on evaporation and partly on the nature of the materials on which the rain falls. The amount of run-off or discharge in the drainage areas of the two principal river systems of the State is as follows: Kennebec, 22.4 inches; Androscoggin, 24.2 inches.

Absorption.—The rainfall that is not removed by evaporation or by run-off into surface streams is absorbed by the soil or rocks with which it comes in contact, either directly or after being gathered into streams. In the first case the rain falls on the surface of the rocks or on the loose unconsolidated deposits lying upon them, and is either soaked into their pores or passes into the fissures and cavities which may be present in the harder materials. In the second case

the water flows into the streams, and from these it may seep into the rocks in which their channels lie, but this seldom occurs in Maine. In either case the unconsolidated materials lying upon the rock surface are saturated to a certain level, and the rocks upon which they lie are in this way kept in contact with water, which is continually being absorbed.

When water enters sands and gravels the direction of movement in moderately moist regions like southern Maine is generally toward the river rather than away from it, but in arid regions, where the rainfall is slight, waters are often absorbed by the gravels in the beds of streams which have come from regions of greater rainfall.

MODE OF OCCURRENCE.

Water occurring in sands, gravels, and other surface deposits is generally held in the pores, or spaces between the pebbles or smaller particles. In certain types of solid rocks, as some sandstones, conglomerates, and very porous limestones, water occurs in the same way, saturating the entire rock below the level of the water table. Most rocks found in Maine, however, are so hard, compact, and close grained that the amount of water contained in the pores is very small. In such rocks practically all the water is held in various forms of crevices, cavities, and fissures. In the slates and argillaceous schists which underlie a large part of the area under discussion, considerable water is held in the bedding and cleavage planes. In granite, gneiss, slate, schist, and most other hard rocks the largest amounts are contained in joint cracks—fissures which cut the rocks in various directions. Where rocks have been faulted—that is, where one wall of a fissure has been moved up or down or horizontally with reference to the other wall—lines of springs sometimes follow the fault where it cuts the surface. In limestones large amounts of water occur in solution cavities which have been dissolved by slow water percolation.

AMOUNT OF GROUND WATER.

General statement.—The amount of water held in the rocks or other materials composing the earth varies greatly, owing to many causes. The amount absorbed depends on the porosity of the material, the slope of the surface, and the size and abundance of joint cracks, fissures, and cavities. The amount of water in drift or surface materials is dependent to some extent on the nature of the underlying rock, and the amount which finds its way into the solid rocks is dependent on the thickness of the overlying surface deposits.

Amount of absorption.—The amount of water absorbed is dependent chiefly on the nature of the materials. The more porous beds of sand and gravel that occur as drift deposits along stream valleys, lake

shores, and the coast absorb very large amounts. Next to these unconsolidated deposits, the rocks which present the conditions most favorable for direct absorption are sandstones and certain porous limestones. The direct absorption by granites, slates, and other massive rocks is very slight. In a general way porosity is determined by the amount of water which the rock is capable of absorbing. A cubic foot of sand will absorb on an average about 10 quarts of water, and certain porous sandstones will absorb 2 to 6 quarts.

Upper and lower limits.—In general it is necessary to dig only a few feet to reach a zone saturated with water. The upper limit of this zone is known as the water table, and the water saturating the materials is known as ground water. The general relations of water table and ground water are shown in fig. 2. The depth to the water

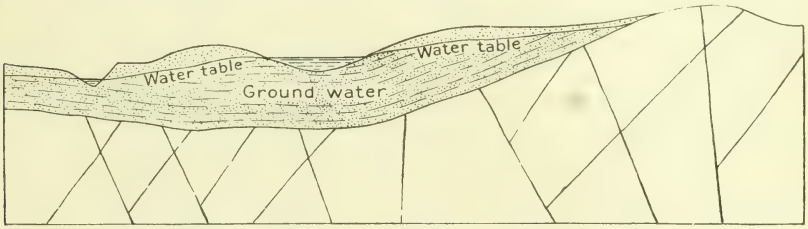


FIG. 2.—Diagram showing relation of ground water and water table to outcrop and bed rock.

table is dependent principally on the amount of precipitation, being least in regions of much rainfall and greatest in arid regions. While there is no definite lower limit to the penetration of water, it is probable that little surface water penetrates more than 3 miles below the surface, and most of the pores and crevices in rocks are closed below the depth of a few hundred feet.

Total amount of ground water.—The total amount of water contained in the earth's crust has been estimated by different writers with widely different results. The most recent estimate is given by Fuller,[a] who concludes that the total amount of free water in the earth's crust would be equivalent to a uniform sheet over the entire surface of the earth with a depth of about 100 feet. This is but a small fraction of the estimate made by other writers.

ULTIMATE DISPOSITION OF GROUND WATER.

The water held in the rocks of the earth's crust disappears in a number of ways. A small portion enters into the chemical composition of the rocks. Small amounts are absorbed by forests and other vegetation. Some of the water reaches the air through capillarity and is evaporated. The largest amounts reach the surface by

[a] Fuller, M. L., Total amount of free water in the earth's crust: Water Supply Paper U. S. Geol. Survey No. 160, 1906, pp. 59–72.

hillside springs and through seepage to neighboring streams. In settled regions large amounts serve as contributions to wells. It is the two last-mentioned portions and the portion still remaining below ground with which we are concerned in this report.

TEMPERATURE OF UNDERGROUND WATERS.

In all wells there is a certain depth, which differs in different localities but is commonly from 50 to 60 feet below the surface, at which there is practically no variation in the temperature of the water from season to season or from year to year. The temperature at this depth is known as the normal temperature of the water for a given locality, and it agrees very closely with the mean annual temperature of the same locality.

In southern Maine the normal water temperature is 40° to 47°. Waters occurring nearer to the surface than the zone of uniform temperature vary in temperature according to season, being warmer than the normal in summer months and colder in winter months. Below the depth of normal temperature the temperature increases, owing to the internal heat of the earth, the average increase being about 1° in every 50 feet. A temperature higher than that which would be expected at a given depth may be due to the derivation of the water from a deep source, but as no thermal springs are known in Maine this cause is not believed to prevail. Where an abnormally high temperature is found in summer it is generally due to the mixture of surface water with the deep-well water, either by leakage along the casing or by penetration downward through joint cracks.

Many determinations of deep-well temperatures have been made throughout Maine, and are found to vary from 45° to 54°, being commonly somewhat higher than the normal. The most common temperature was 47°. In this State the temperature seems to hold no definite relation to the depth of the well, as would be expected; the reason is supposed to be that water in most rock wells in Maine is derived from more than one vein, and the principal supply is not invariably at the bottom of the well. In any well not properly cased surface water may enter and raise the temperature above the normal. The true temperature of a well water can be found only by pumping several minutes before taking the measurement, to exhaust the water which has become either heated (in summer) or cooled (in winter) in the piping.

The temperature of a well water is frequently a factor of considerable importance to the users. In a number of pulp mills in Maine well waters are used for cooling acid. They are also used in creameries for cooling cream, and for ordinary drinking purposes it is more pleasant to have a cool water. Practically all rock waters in Maine are cool enough for drinking, but in some dug wells the water is warmer

than the average. Deep-well water whose temperature is higher than 50° is open to suspicion; it is probably in part surface water.

QUALITY OF UNDERGROUND WATERS.

General statement.—Rain water falling near the close of a storm, after the impurities have been dissolved out of the air, is very nearly pure H_2O. As it finds its way below the surface, however, into the soils and surface deposits it dissolves and holds in solution small quantities of organic and mineral matter. Normally in the country districts, where the ground water does not come into contact with polluting materials in its downward passage, it dissolves only a small amount of organic matter, but takes into solution some mineral matter. As the water moves downward still farther and enters the underlying solid rocks large quantities of mineral matter may be taken into solution. In Maine the quantity of mineral matter is seldom more than 200 to 500 parts per million, and this does not affect the safety of the water for drinking purposes. In towns, however, and in the vicinity of houses, barns, refuse heaps, privies, and cesspools, considerable amounts of polluting organic matter are dissolved by the ground water, and such water is dangerous for domestic supply.

Source of mineral matter.—Polluting organic matter always comes, directly or indirectly, from the surface. Mineral matter, however, may enter the water in a number of ways. In most parts of the State it is practically all dissolved from the rocks or other materials in which the water is found or through which it has passed. For this reason water in limestone and calcareous slate, the materials of which are easily soluble, contains large amounts of mineral matter, whereas water in such rocks as granite and ordinary clay slate contains less amounts. Certain mineral constituents, as nitrites, nitrates, and chlorine, are frequently derived from organic matter, and therefore their presence in abnormal quantities is an indication of pollution. In some wells on islands or near the ocean the amount of mineral matter is found to be very high, frequently running up to several thousand parts per million. Such proportions are sometimes due to a mixture of salt water which has entered from the sea.

Normal chlorine lines.—One of the best indications of the source of water, especially of surface water, is chlorine. This element, a constituent of common salt, is present in nearly all natural waters. Its original sources are certain mineral deposits and finely divided salt spray from the sea. This sea spray, which is of most importance as a source of chlorine in Maine, is carried inland with dust particles and precipitated with the rain. The chlorine decreases as waters farther and farther inland are tested, and hence it has been possible to make determinations and prepare a map giving lines of equal chlorine

which represent the normal percentages throughout the State.[a] All salt found in water not derived from mineral deposits or from the sea comes from domestic drainage and indicates that the water either is at the present time polluted or was polluted and has since been purified. For surface waters the normal chlorine lines hold with great accuracy. For most underground waters, however, owing to the occasional presence of chlorine in rocks and to the frequent circulation of water to localities of different normal chlorine, the map is of little value, and should not be depended on except when considered together with other evidence.

WATER-BEARING ROCKS OF MAINE.

PRINCIPAL TYPES.

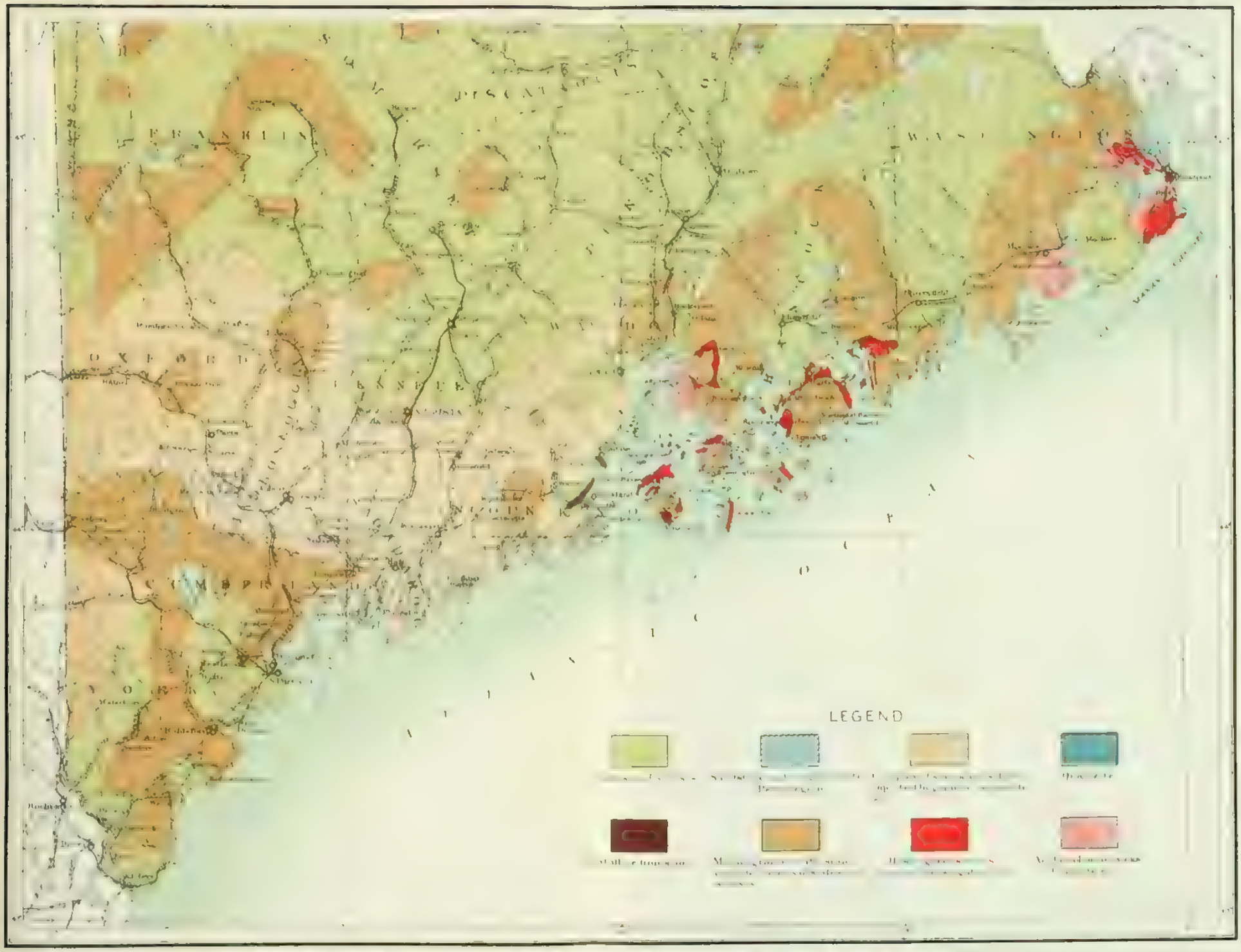
General statement.—All formations contain more or less water, which, as has been pointed out, occupies cavities or crevices in the rock or is held between the pores. The principal rocks in southern and eastern Maine are granites, gneiss, slate, schists, and surface volcanic rocks, with a few small areas of limestone, quartzite, and other rocks. Overlying these are usually surface deposits, consisting of sand, gravel, glacial till, and marine clays.

Relation to underground waters.—The amount and the nature of the water occurring at any locality are dependent on the kind of material in which it occurs. The distribution and character of water in various materials are summarized in the following table:

Summary of occurrence of water in rocks and surface deposits of southern Maine.

Material.	Distribution.	Water supply.
Granite	Irregularly distributed over large areas.	Plenty of good water at moderate depths, but held entirely in irregular joint cracks at variable distances apart.
Gneiss	do	Do.
Slate	Forms more than one-third of the area.	Generally plenty of good water. Occurs in irregular joint cracks, and to a moderate extent along highly inclined cleavage and stratification planes.
Schist	Irregularly distributed in slate and gneiss areas.	Do.
Limestone or marble	Chiefly in Knox County, but existing also as thin bands in slate areas generally.	Abundance of hard water, chiefly in solution cavities.
Trap and volcanic rocks	Occur in several relatively small areas.	Small amounts of water, which are mostly rather high in mineral matter, but in some wells are as good as granite waters.
Unmetamorphosed sedimentary rocks.	Perry Basin, eastern Washington County, and other small areas	Not tested, but probably contains plenty of water of good quality.
Gravel and sand	Widely distributed, especially in the valleys, 1 to 100 feet thick.	Large amounts of water. Of good quality where not polluted.
Till or bowlder clay	Covers the bed rock nearly everywhere, in many places underlies gravel and sand.	Water of variable amount and quality.
Clay	Locally distributed in the valleys and along the coast.	Contains little available water

[a] Jackson, D. D., Water Supply Paper U. S. Geol. Survey No. 144, 1905, Pl. II.



MAP SHOWING DISTRIBUTION OF ROCKS IN SOUTHERN MAINE SO FAR AS KNOWN

Based on reconnaissance and detailed maps by Geo. Otis Smith, E. S. Bastin, F. G. Clapp, G. C. Matson, and C. W. Brown

DETAILED DESCRIPTIONS.

GRANITE AND GNEISS.

Description.—The granites and gneisses are very hard, dense, coarsely crystalline acidic rocks, and possess as a rule only microscopic pores. Granite being one of the hardest of rocks, drilling in it is difficult. Commonly a well in this rock is not deepened more than 3 to 5 feet a day, and sometimes not more than a few inches a day.

Distribution.—These rocks are widely distributed in Maine. Their boundaries are so irregular that their limits are best defined on a map rather than in a general description. The granite is represented by the brown color on Pl. I. There is some granite in nearly every part of southern and eastern Maine, but the largest areas are in Washington, Oxford, Cumberland, and York counties. As stated in the legend, areas covered by the granite symbol on the map include some small masses of a somewhat more basic rock, similar to granite, but of a darker color, known as diorite, and also moderate areas of gneiss, a somewhat banded type of granite, and of pegmatite, a rock of granitic composition but of very irregular and coarse texture.

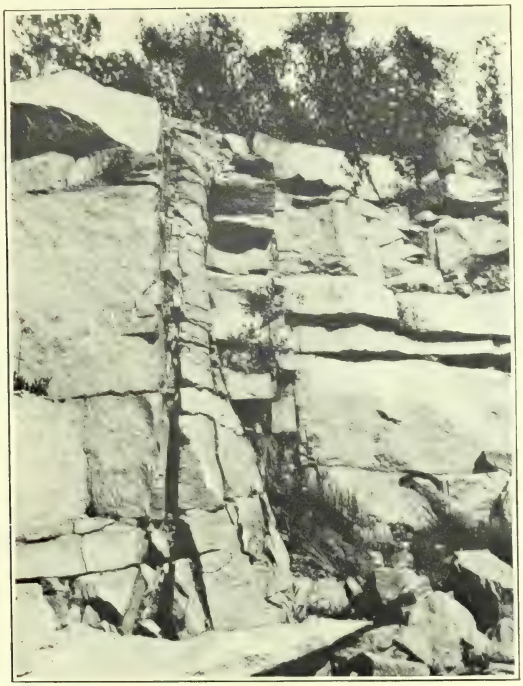
Relations to other rocks.—Where the granite occurs in large areas it extends downward to an unknown depth. In late Silurian or Devonian time the granites and gneisses, in a molten condition, were intruded into the sedimentary rocks which existed at that period. In many localities, as in York and Cumberland counties, the granite can be seen cutting across and inclosing masses of slate. An instance of this relation is seen in Pl. X, *B*, which shows a thin band of granite parallel with the stratification of the slate, the whole rock being much metamorphosed.

Joint cracks.—Practically all the water found in granite occurs in joint cracks. These joints generally form complex systems of intersecting planes (figs. 2 and 4). In southern Maine there are two principal systems. One of these—the horizontal joints, sheet joints, or "beds"—is approximately parallel with the surface of the ledge. Near the surface these joints are only a few inches apart, but they become many feet apart with increasing depth. In the J. C. Rogers well No. 1, near Stonington, 27 distinct "beds" of rock were penetrated in a depth of 94 feet. These ranged in thickness from a few inches to 14 feet. The thickest bed was passed through about midway from top to bottom in the well. The joints that are not sheet joints run in all directions, but in southern Maine the great majority of them, including the most persistent series, strike between N. 70° E. and S. 50° E. The hade of the joints, or the angle which they make with the vertical, varies, but except in the sheet joints it is generally small—from 0° to 30°. A zone of these vertical joints is illustrated in Pl. II, *A*.

Structural relations of granite.—The structure of the granite in Hancock County, where it is extensively quarried, is typical of Maine granites, and its peculiarities will therefore be discussed in some detail. A number of quarries were visited with a view of obtaining information regarding the relations of rock structure to occurrence of water. In the quarries at Brooksville the principal system of joint cracks strikes S. 80° E. These joints are very numerous and persistent and are nearly vertical. They are, however, not open except near the surface. The second system, consisting of a few joints only, strikes S. 10° W. The sheet joints slope with the hill and the beds are in general from 1 to 5 feet in thickness. These conditions would seem to afford a good opportunity for water to penetrate downward parallel with the slope of the hill. In all the quarries there are some joints which do not seem to belong to either regular series, and some which are more open and would give a better opportunity for the downward penetration of water. One joint belonging to the principal series exposes an inch of decomposed granite that has been much iron-stained by percolating water. This crack was very wet, owing to water which is now penetrating along it. In some places granite along joint cracks is decomposed for a distance of 2 inches or more from the crack.

In another quarry in the same town the principal system of joints strikes approximately N. 20° W. and hades 25° W. This system is continuous from the top to the bottom of the quarry, which is 20 feet or more in depth. The principal crack is one-fourth inch wide in places. When seen it was a little wet, but not iron stained or decomposed. In this system the joints are from 20 to 40 feet apart. A smaller system runs about east-west and hades nearly vertical. Other vertical joints do not belong to any of the regular systems. These irregular joints are much stained and tightly closed. They are generally from 2 to 10 feet apart and die out as they run against the more persistent joints of the principal series.

At Stonington a great deal of quarrying has been done and the conditions here are fairly typical of the granite on the Maine coast. The general strike and hade of the joints average the same as in other towns. Some cracks are, however, as much as an inch in width. One crack was found filled with a soft, greasy-looking mineral having a cleavage resembling that of calcite. As most of the quarries are on small islands, and some of them extend more than 100 feet below the sea, the sea water seeps in along the general system of joints and collects in the bottom of the quarries, whence it has to be pumped by windmill or engine. The sheet joints in the quarries at Stonington are nearly always dry. They slope toward the sea from the center of the hill, generally being 1 to 2 feet apart at the surface. Some of them are one-fourth to one-half inch in width and are filled with earth and rotten granite.



A. ZONE OF NEARLY VERTICAL JOINT CRACKS IN GRANITE QUARRY.

B. CONCENTRIC WEATHERING IN DIORITE AT PLEASANT RIVER GRANITE QUARRIES, DALOTVILLE.

Showing mode of entrance and storage of water along decomposition planes.

Water supplies.—Fig. 4 gives an example of the general arrangement of joint cracks. It will be seen that it is possible for water occurring in surface deposits to find its way downward to great depths, and that it will be tapped by any well which chances to strike a joint sufficiently open to form a part of the reservoir. The nearly vertical joints (Pl. II, *A*) and decomposition planes (Pl. II, *B*) generally serve as channels for the admission of water; the sheet joints serve as part of the reservoirs in which it is stored. As most of the joints are rather narrow, the amount of water yielded by them is likely to be only moderate, as a rule not more than 10 gallons a minute. Occasionally, however, as much as 30 gallons a minute has been obtained with a steam pump. The occurrence of water in granite is well illustrated by Pl. III, which shows water flowing from sheet joints in quarries at North Sullivan and Jonesboro. Similar flows have been observed at numerous quarries in Maine. In the R. A. Small well at Lisbon Falls a hand mirror was used to examine the bottom and sides of the well at frequent intervals during drilling, and water was seen to enter from all the sheet joints. In a few granite wells no water has been found.

On account of the extreme irregularity of joints in granite it will be seen that the success of any well in this rock is largely a matter of chance, dependent on whether the location is a fortunate one with reference to the arrangement of the joints. Fig. 4 shows how a well may (*a*) strike plenty of water within a few feet or (*b*) go to a great depth without success. Where the joints are numerous an increased amount of water may be found by deeper drilling, but in some places such continued drilling has found open cracks through which the water ran away.

As joints are most common near the surface and diminish in number as the depth increases, and as the pressure tends to make them close up with depth, the water supplies in granite are generally found within 100 or 200 feet of the surface. In an investigation of water in the crystalline rocks of Connecticut, Ellis[a] concluded that as a rule it does not pay to drill below 200 feet. A prominent well driller of Maine who has drilled many wells in granite, in a calculation based on his experience, found that the average depth of the principal vein of water was 185 feet. While successful wells in which the principal vein is at a greater depth are often found, the probability of success by drilling below 250 feet seems to be less than it is by "pulling up" and starting a new well a few feet away. On account of the irregularity of the joints the new well is no less likely to be successful because a drilling near by has proved unsuccessful. One well drilled in gneiss at Auburn went to a depth of 654 feet without encountering any water. Few wells are complete failures, however.

[a] Ellis, E. E., Water-Supply Paper U. S. Geol. Survey No. 160, 1906, pp. 19–28.

A few wells in granite yield natural flows of water. Usually, however, the water stands some distance below the surface.

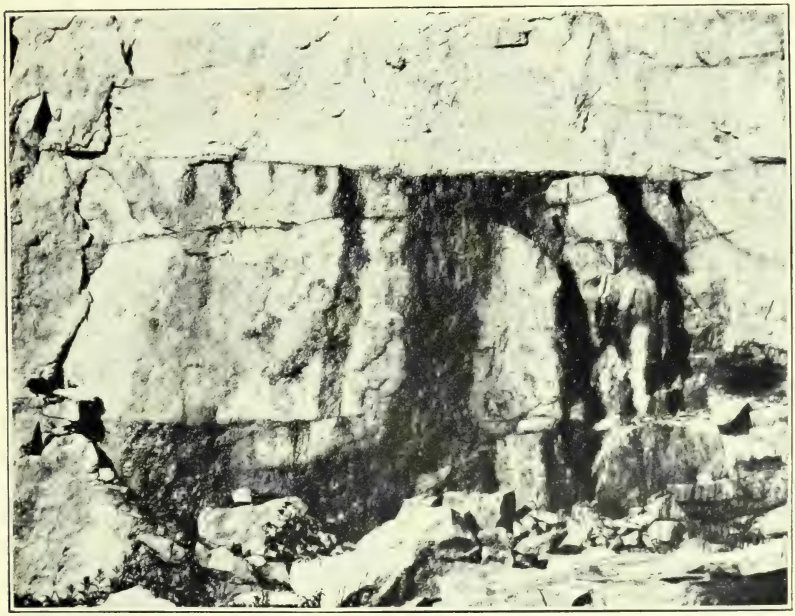
Quality of water.—In quality granite water is as good as the best. The analyses on page 77 show that the total solids range in general from 40 to 200 parts per million, with occasional higher records. Analyses of granite waters from several wells along the coast have shown total solids running up to several thousand parts per million, but these proportions are mostly due to the inward penetration of sea water along open joints. In a few wells the amount of chlorine in granite harmonizes with the normal chlorine for the locality, but in most it is much higher. When this discrepancy can not be accounted for by pollution or by entrance of sea water it is believed that sodium or calcium chlorides exist in the rock. The calcium, magnesium, and sodium in granite are generally low, none of them being known to exceed 70 parts per million, and they are nearly everywhere below 30 parts. The carbonates may run as high as 150 parts, but are here and there as low as 10. Sulphates, if present, range up to 40, and silica from 5 to 30; potassium is not recorded above 10 parts. The general composition of granite water, as illustrated by analyses made in southern Maine, is represented by Pl. IV.

SLATE AND SCHIST.

Description.—The slate found in southern and eastern Maine is exceedingly diverse in character. Most commonly it is a fine-grained, moderately hard, dark-gray to greenish or black rock produced by the consolidation and metamorphosis of clay. In places it grades into true schist. In Aroostook County, southern Penobscot County, and a few other localities the slate is locally slightly calcareous. Practically all the slate in this State is highly folded, and the stratification and cleavage planes stand on edge. Near the coast the strike is variable, but in Kennebec and Penobscot counties it is very constant, being about N. 60° E. over broad areas. The dip is not so uniform, but is nearly everywhere high. As these rocks range from very hard to very soft, the speed of well drilling varies proportionately. Generally 2 to 10 feet a day can be accomplished, but one well is reported to have been sunk 35 feet in a single night.

Distribution.—Nearly half the area covered by this report is underlain by slate and schists. The areas are so irregular that they can not be well described, but they are shown on Pl. I by the green color. Slate is much more abundant in the northern part of the area than in the southern part, and north of the forty-fifth parallel it is still more predominant.

Relation to other rocks.—At many points in York and Cumberland counties and elsewhere the slate and schist can be seen to be cut by granite, proving that the sedimentary rocks in that part of the State



A. SECTION OF GRANITE QUARRY AT JONESBORO.

Showing water issuing from sheet joints.

B. VIEW IN CRABTREE & HAVEY'S GRANITE QUARRY, AT NORTH SULLIVAN.

Showing occurrence of water in sheet joints.

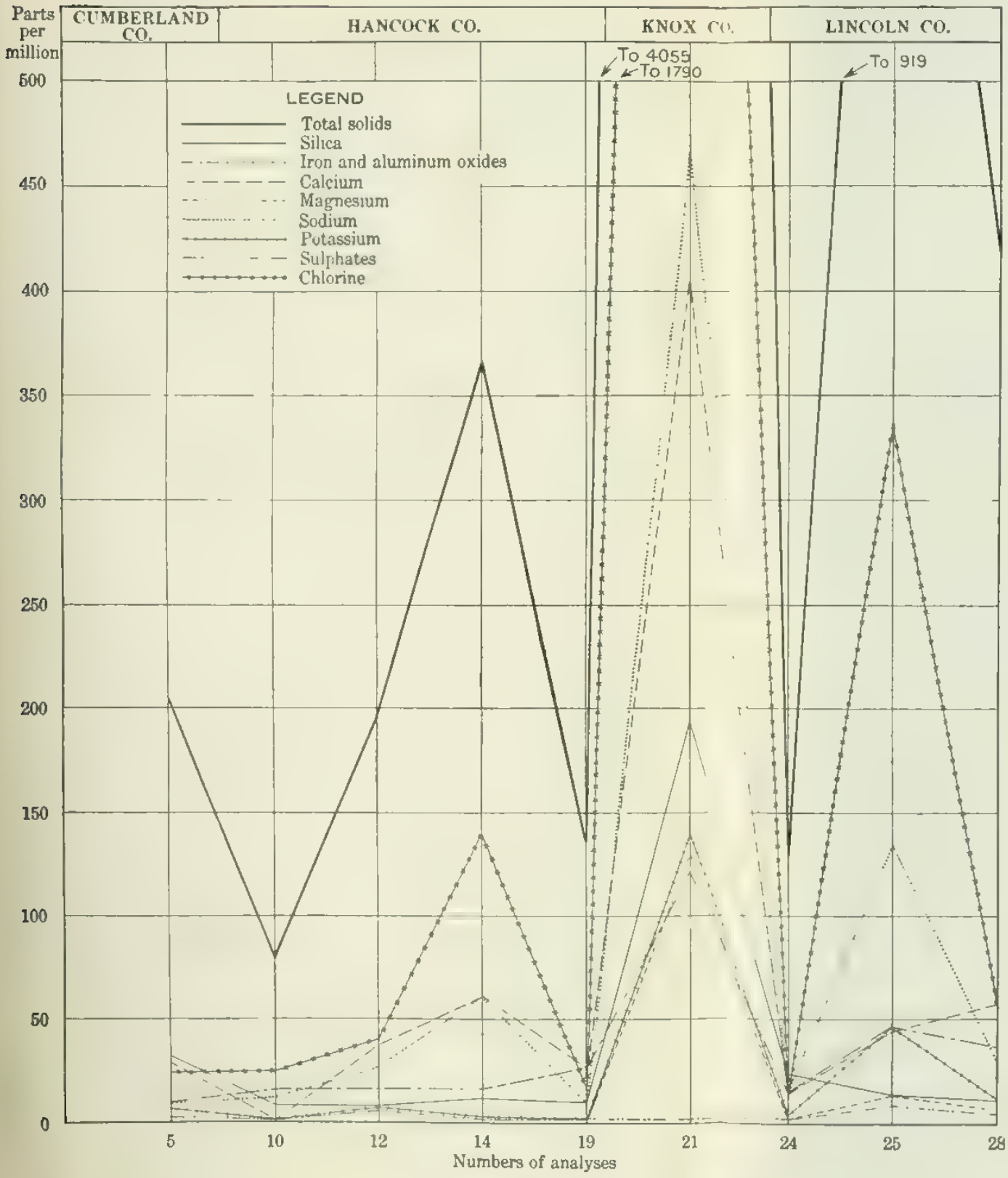


DIAGRAM ILLUSTRATING RELATIVE COMPOSITION OF GRANITE WATERS IN SOUTHERN MAINE.

are older than the principal granite masses. In the Penobscot Bay quadrangle the slate and schist (Penobscot formation) have been shown to be probably of Cambrian age, and most of the similar rocks of southwestern Maine are believed to be of the same age. The Ellsworth schist is slightly older, but may also be Cambrian. All the regionally metamorphosed rocks are Ordovician or older, as the movements which produced metamorphism took place about the close of Ordovician time. The high folding and extensive metamorphism of these rocks over wide areas make them all of the same class so far as the underground-water conditions are concerned.

Stratification, cleavage, and fissility.—The slates over most of Maine show clear evidences of stratification, but have been subjected to so great pressure that the dip is everywhere at a high angle, generally within 30° of the vertical. The strike along the coast is somewhat variable, but throughout most of Kennebec and Penobscot counties it is rather constant, in few places departing much from N. 60° E. Most of the slate and schist is rather easily cleavable, and as a rule the cleavage and foliation planes correspond in strike with the stratification, but vary somewhat in dip. The cleavage, foliation, and stratification planes are generally tightly closed at considerable depths, but rather open near the surface, and in many regions they allow passage for small quantities of water.

Joint cracks.—What has been said regarding joints under the description of granite will also apply in a general way to slate and schist, except that in these rocks the cracks are more irregular in direction, extent, and characteristics. On account of the difference in structure of slate, its joints are not conspicuous, but they can be depended on for water supplies. Where they are flat, they have little effect on drilling, but in numerous places the slate is much cut up by joints, many of which are inclined. These often work havoc with drilling tools. If an inclined joint plane is hard and smooth, the drill may glance off and give a crooked hole. If the joint plane is soft, the drill may get stuck, and sometimes many days are required to remove it, or the hole may have to be abandoned altogether.

Water supplies.—Slate is generally supposed not to contain much water, but in Maine it has proved to be the most productive rock. As in granite areas, the water is first stored largely in superficial deposits of gravel and bowlder clay. In the slates and schists, however, the water penetrates downward not only through joint systems but also along small fissures which follow the stratification and cleavage planes. An illustration of the way water may find its way below the surface from overlying drift is given in Pl. V, *A*, and Pl. VII, *A*, the first view showing the effect of stratification planes and the second of joint cracks.

On account of the more numerous means of admission of water larger quantities are generally expected and found in slate than in granite. Few wells drilled in slate in southern Maine have met with absolute failure. Instances in which only a gallon or two of water a minute has been found are due generally to the insufficient depth of the well.

The depth to which it is advisable to drill in slate differs somewhat in various parts of the State. In some places along the coast and near the areas of intruded igneous rocks, where the slate has evidently been under great pressure, the statement made with regard to granite, that it is not desirable to drill deeper than 250 feet, seems to hold true. In the large slate areas of the interior, however, wells drilled much deeper than that seem to afford supplies which increase with depth. Some of the best wells in the State are more than 300 feet deep, and so far as known there have been no failures among these deep holes. Hence in the large slate areas it is well to drill as deep as 400 or 500 feet unless sufficient supplies are obtained nearer the surface. In general, the water in slate is not all obtained in any one vein, but small supplies are found in a number of veins, and it is by the repeated tapping of new veins that a sufficient supply is finally obtained. The amount of water supplied by most slate wells less than 100 feet in depth is between 1 and 10 gallons a minute. In many of the wells of greater depth, however, the supplies run up to 30 gallons a minute, and in a few localities, as at Searsport, wells pumped by steam pump have been reported to yield more than 50 gallons a minute.

A prominent well driller of Aroostook County calculates that in that part of Maine the average depth of wells is 81 feet. In Bangor and vicinity drilling frequently has not been successful at first, but rather than go deeper the driller has moved the machine 5 to 10 feet and a good supply of water has been obtained. Such cases resemble the occurrence of water in granite.

That large open cracks exist in slate is proved at Sorrento, where two salt-water wells were obtained on a peninsula, indicating the penetration of sea water inward from the ocean. In Islesboro cracks and cavities are numerous. These are most common 30 to 40 feet from the surface, and few occur below 100 feet. They are supposed to be due to the solution of beds of limestone, and the permanent supplies from this source are only 2 to 3 gallons a minute.

The best and largest supplies in southern Maine are obtained in slate and schist below 100 feet.

The head of water in slate is very uncertain, depending on the topographic situation of the well and the arrangement of the systems of water passages in the rock. The water level may stand anywhere between the bottom and top of the well, but is commonly a few feet below the surface.

A. OUTCROP OF SLATE IN RAILROAD CUT AT KITTERY JUNCTION.

Showing fracture of rock along bedding and possibility of water entering from overlying drift.

B. COMPLETED WELL BELONGING TO CRABTREE & HAVEY, AT NORTH SULLIVAN.

Showing proper mode of protection of well drilled in granite.

Strange as it may seem to those who know the structure of slate, a few flowing wells have been struck in this rock. Such wells do not appear to have any regular distribution, and there are in general not more than one or two in a town. Two of them are in Westbrook, two in York, two in Islesboro, one at Bangor, and several elsewhere in the region. The flow seldom exceeds 3 gallons a minute. It is generally caused by the pressure of water following downward along systems of joint cracks from neighboring hills (see fig. 4), and the water rarely, if ever, in this region comes from a distance. The best flowing wells in Maine are at Greenville, Piscataquis County, where there are several from which the water will rise 10 to 14 feet above the surface. These will be described in the report on the underground waters of northern Maine.[a]

Quality of water.—In quality the slate water of southern Maine may be said to be the best for drinking purposes, and except in Waldo and Penobscot counties it is seldom hard. According to the analyses which have been made (see pp. 78–80), the total solids run from 25 to more than 800 parts per million. In order to show graphically the general character of slate water Pl. VI has been prepared. A separate line is given for each constituent of the water, and it will be seen that there is some similarity in the composition of the water from different localities.

Occasionally the water found in slate contains small quantities of iron, but these are rarely sufficient to be objectionable. In Waldo and Penobscot counties the amount of calcium and magnesium carbonates is high and produces some scale in boilers. Waters in these counties are generally called "hard," but are only of moderate hardness when compared with many waters in the Central States that are used for a great variety of purposes.

LIMESTONE.

Character and distribution.—In southern Maine the limestones are restricted to a type of dense crystalline limestone which is found practically only in Knox County, in the towns of Rockland, Rockport, Camden, Thomaston, and Warren. The rocks consist of a number of bands of limestone associated with slate, schist, and quartzite. (See Pl. I.) These bands are not more than a mile in greatest width and extend in a general northeast-southwest direction. In Islesboro there are local beds of similar limestone, all very thin and interstratified between vertical slates. These thin limestones of Islesboro are unimportant, except as they furnish a large proportion of calcium carbonate in the water and interfere with well drilling. The distribution of the limestones of Knox and Waldo counties is

[a] The report for the northern part of the State is in preparation.

shown in detail in the Rockland folio.[a] These limestones are believed to be all a part of the same geologic series, and were formed at the same period as most of the slates of central Maine and of Waldo and Knox counties.

Solution cavities and channels.—The waters in limestone occur mainly in open channels, caverns, etc., dissolved in the rock by the water itself. The water probably originally followed joint or bedding planes, which were gradually enlarged by solution and formed the cavities that we now find. One of these channels, exposed in the side of an abandoned quarry, is illustrated in Pl. VII, *B*. The occurrence of these channels within the limestone is very irregular and their location can seldom be predicted. Most deep wells drilled in the limestone, however, will probably encounter one or more such passages.

Water supplies.—The waters in limestone are hard but are not commonly mineralized in other respects. There is a considerable likelihood of pollution, owing to the fact that much of the underground water occurring in limestone has found its way downward through definite channels and has carried with it more or less surface wash. A single analysis of limestone water is given in the table on page 86 (No. 255). This water was collected from a spring in the bottom of a deep quarry near Rockland. No other analyses were made, as no wells have been drilled in limestone (except wells on Islesboro, which are largely in slate but pass through thin layers of limestone). The large amount of water pumped daily from these quarries and the common occurrence of springs in them indicate the probable existence of considerable quantities of water in these rocks.

At Islesboro the drillers report numerous cracks below 50 feet in depth, and occasionally pockets 3 to 4 feet in size are found. These generally supply abundant water for a few minutes or hours, but the supply soon gives out, so drilling is never stopped at a pocket. Although these wells are in a slate region, the pockets are supposed to occur in thin beds of limestone which have been partly dissolved.

VOLCANIC AND OTHER IGNEOUS ROCKS.

Character and distribution.—In the extreme western part of Hancock County, on many of the islands in Penobscot Bay, on the southern edge of Mount Desert Island, and in eastern Washington County, there is a class of rocks represented on the map (Pl. I) by the red color. These rocks are principally volcanic in origin and consist of flows of andesite, rhyolite, diabase, etc., and of beds of tuff or volcanic ash. On a map of this scale it is not possible to represent all the various types of these rocks, even if the limits of all the areas were definitely known. In Hancock and Knox counties the mapping

[a] Geologic Atlas U. S., folio 158, U. S. Geol. Survey, 1908.

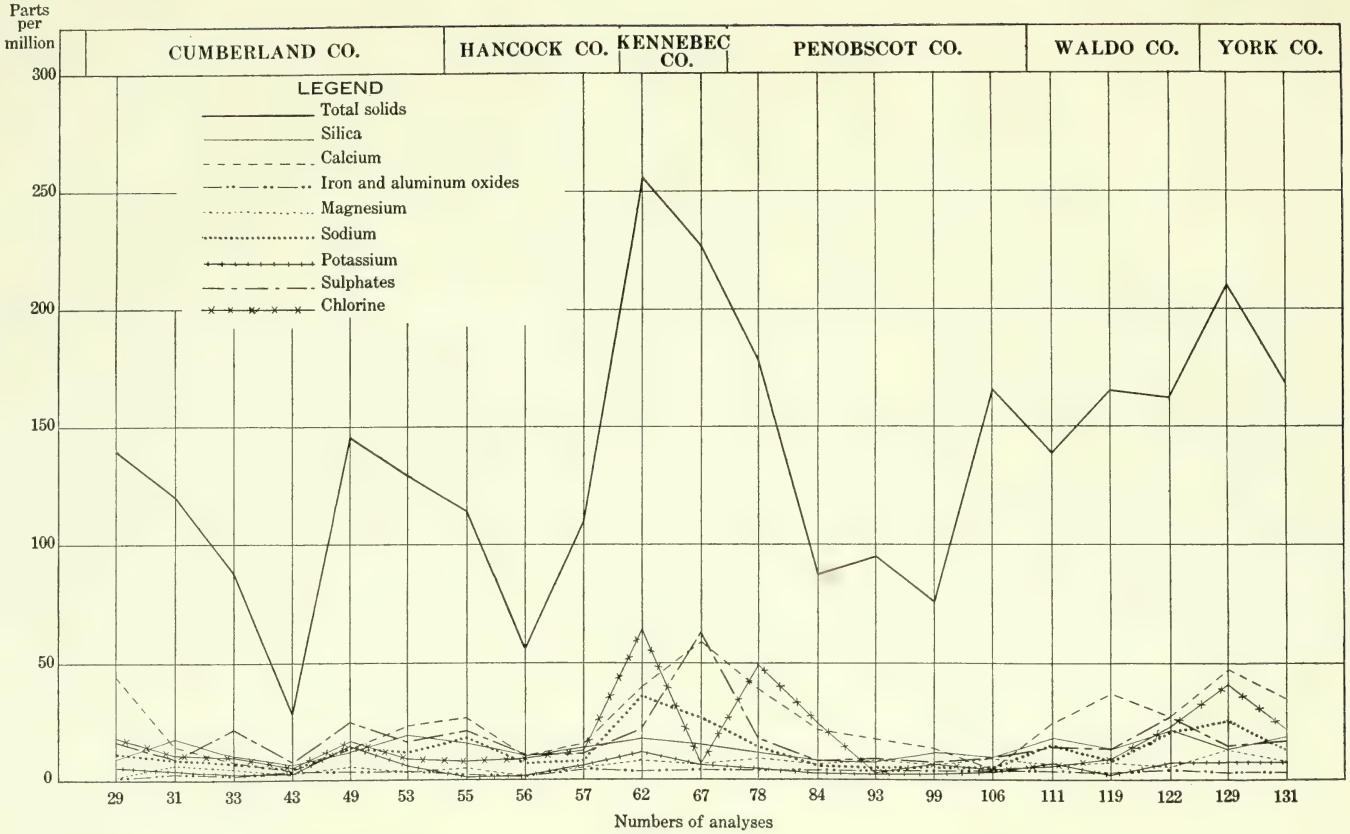


DIAGRAM ILLUSTRATING CHEMICAL COMPOSITION OF WATER FROM SLATE IN SOUTHERN MAINE.

A. OUTCROP OF SLATE BELOW TILL IN RAILROAD CUT AT KITTERY JUNCTION.

Showing vertical joint cracks and overlying cover of till in which water is held.

B. SMALL CAVE AND SOLUTION CHANNELS IN LIMESTONE.

Showing old water passages, Rockland.

is based on the detailed maps of the Penobscot Bay folio.[a] In Washington County the limits of the volcanic rocks are not so accurately known.

Besides the areas of volcanic rocks represented on the map, there are small dikes of trap rarely more than a few feet in width. These are intrusive in the slate and granite throughout the coast region, and are geologically among the most recent rocks in the State.

Water supplies.—On account of the manifold nature of the volcanic rocks, no comprehensive statements can be made concerning the water supplies they contain. Wells in these rocks are, however, much less sure of success than those in granite. In Castine several wells drilled in acidic volcanic tuff obtained moderate supplies, but one was an entire failure. In a 625-foot well at this place no water was found below 425 feet. At North Haven several wells drilled in basic lava flows get fair amounts of water, but some wells here were but partially successful. On Suttons Island, off Mount Desert, a well in trap is reported to yield 26 gallons a minute when pumped with a gasoline engine, but wells on neighboring islands were either unsuccessful or obtained only from 1 to 5 gallons a minute. At Eastport and Lubec several wells sunk in greenstone seem to give moderate amounts. One well at Eastport was a flowing well.

Quality of water.—On account of the small areas covered by these rocks in Maine only half a dozen analyses have been made. These are given in the table on page 81 and are represented graphically in Pl. VIII. It will be seen that the one greenstone water analyzed showed 413 parts per million of total solids, of which 108 were calcium, 42 were organic and volatile matter, and 71 were sulphates. A field assay of the same water showed 214 parts of bicarbonates, this being about as hard as the average of the slate waters in Penobscot County. The first analysis of trap water (No. 155) is so high in mineral matter that it is supposed to be partly sea water, and should not be considered as typical of trap waters in general. The second analysis of trap water is more moderate, showing only 90 parts of total solids. The proportions of the various elements in this water are very low for a well water. When trap waters are used they seem to be fairly good for both drinking and washing.

UNMETAMORPHOSED SEDIMENTARY ROCKS.

A few small areas in eastern Maine are occupied by unmetamorphosed sedimentary rocks, but only one of these—Perry Basin, in eastern Washington County—is of sufficient size to be mapped. (Pl. I.) This area is described by Smith.[b] The rocks were found to be conglomerates, sandstones, and some interbedded rhyolitic

[a] Geologic Atlas U. S., folio 149, U. S. Geol. Survey, 1908.
[b] Smith, G. O., Prof. Paper U. S. Geol. Survey No. 35, 1905.

lavas. They are of Devonian age, and were named the Perry formation. No drilled wells are known to have been sunk in these rocks, and hence little is known of the underground water conditions. To judge from similar rocks in other localities, they ought to hold plenty of water of good quality. In the same region are considerable areas of Silurian shales.

AREAS OF COMPLEX.

Character and distribution.—On Pl. I large areas in Oxford, Androscoggin, Sagadahoc, Lincoln, Knox, and Waldo counties and portions of adjacent counties are represented by a buff color. These areas are occupied by what is known as a complex, consisting of slates and schists intimately intruded by granites, gneisses, and basic volcanic rocks. The rocks in eastern areas, or those lying east of Brunswick and Augusta, are more slaty, and those in the western areas are more granitic, but they can not be differentiated on the map.

Water supplies.—As a rule water from areas of complex that are of notable size is more uncertain in quantity and quality than that from either granite or slate. Some good wells have been obtained in these areas. In many wells in Lincoln county the water has a peculiar taste, which sometimes makes it unfit for use. The water is known to have a bad effect on the well casing, frequently eating holes through it in a surprisingly short time, and the solution of the galvanized iron may possibly be a factor in the taste of the water. In some wells the taste may be due to iron, but as iron is absent in the greater number of these waters, this is not the chief cause. A review of the analyses of waters from the complex (p. 81) shows that they average higher in sulphates than those from either granite or slate. This indicates that they may contain free sulphuric acid. The sulphates range from a trace up to 77 parts per million. One field assay reports 286 parts per million. The total solids run from 95 to 301 parts per million in samples which were tested for them. As a rule the waters in the more granitic portion of the complex area are rather poor in quality, containing considerable iron and other minerals, whereas that from the more slaty portion is better.

SURFACE DEPOSITS OF SOUTHERN MAINE.

PRINCIPAL TYPES.

The surface deposits in Maine consist of stratified and unstratified clay, sand, and gravel and of till or bowlder clay. With the exception of some modern beaches, these surface deposits, which are known collectively as "drift," were laid down directly or indirectly through the agency of vast continental glaciers that covered New England at several periods during the last million years. Materials

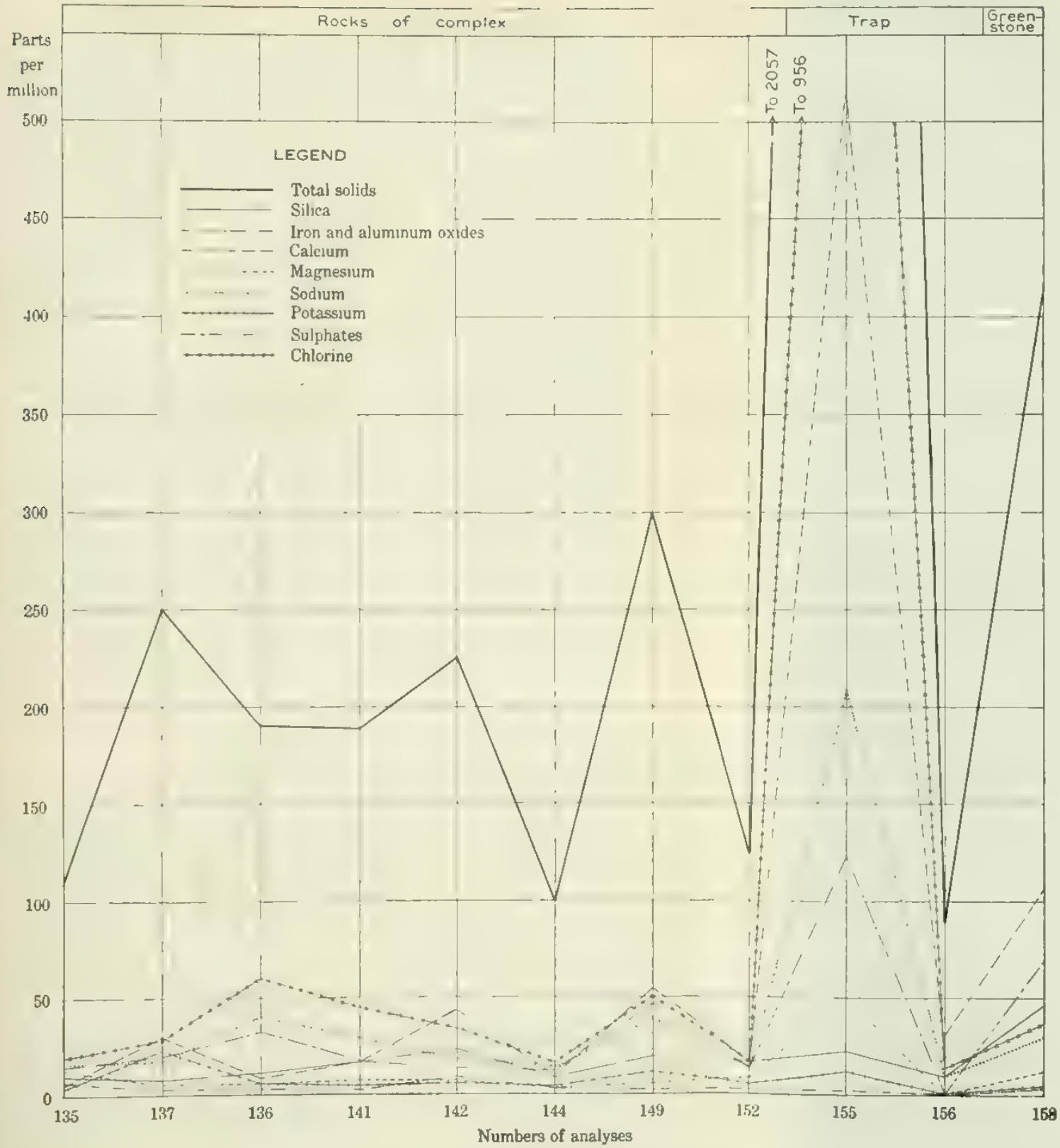


DIAGRAM ILLUSTRATING RELATIVE COMPOSITION OF WATERS IN AREAS OF COMPLEX, TRAP, AND GREENSTONE IN SOUTHERN MAINE.

formed by the grinding action of the ice in passing over the rocks and former surface deposits were, when the ice retreated, left as the heterogeneous deposits of till or bowlder clay which now cover large areas in both the uplands and the valleys. During the occupation of the region by ice, glacial rivers laden with sand and gravel flowed upon or under the ice, and the deposits made in their channels now appear as long, winding gravel ridges, known as "eskers." During the times when the ice was stationary great quantities of sand and gravel were often discharged into the sea, into glacial lakes, or onto the land surface to form deltas and sand plains. Irregular water-laid deposits, formed in connection with the ice, are known as "kames." When the ice finally melted it did not retreat steadily, but often halted, perhaps for years at a time, and during such halts a ridge or a succession of hills of sand, gravel, till, and bowlders was sometimes formed at the ice front, of material pushed up by the glacier or deposited by glacial waters. Such deposits are known as "moraines."

The writer has found evidence that since the first glaciation there have been interglacial periods.[a] During such an interglacial stage the land seems to have stood at a lower level than at present, and there was deposited in the sea a widespread bed of stratified clay, which now extends for great distances along the coast and more than 100 miles up the larger valleys. This has been known as the *Leda* clay, from a species of fossil shell which it contains.

In order that the occurrence of water in the surface formations may be well understood, they will be described in some detail, in the order in which they originated.

DETAILED DESCRIPTIONS.

BOWLDER CLAY, OR TILL.

Character and distribution.—Bowlder clay, or till, is the principal drift deposit of Maine. It consists mainly of a heterogeneous deposit of clay, sand, gravel, and bowlders, showing as a rule no trace of stratification and containing bowlders up to several feet in diameter. Its thickness ranges from a few inches to more than 100 feet. Usually it is very hard and tough, and is called "hardpan," though this term is also applied by well drillers to other formations.

This material is probably the most widespread deposit in Maine, overlying the bed rock nearly everywhere, and generally underlying the surface sand, gravel, and clay deposits, where the latter are present. In places in southwestern Maine till occurs segregated in the form of lenticular hills, known as "drumlins." These are often from one-fourth mile to a mile in greatest length and 100 to 200 feet in height, and are composed entirely of the hardpan type of bowlder clay.

[a] Complexity of the glacial period in northeastern New England: Bull. Geol. Soc. America, vol. 18, 1908, pp. 505–556.

Water supplies.—Where typical and occurring in thick deposits, as in drumlins, bowlder clay can not be said to yield a large amount of water. Wells dug in drumlins are generally dependent on surface water and frequently run dry in summer. The scantiness of the supply in drumlins is due to the large proportion of clay in this type of till, rendering it impervious. Where the till fills depressions and covers gentle slopes, however, it is in many places of more variable character, locally containing gravelly and sandy layers, and here and there having openings which form rather definite water channels. For this reason the degree of success with wells in till varies greatly, but in the aggregate the till yields a large amount of water. Generally wells of large diameter are most successful, as they offer a better opportunity for intercepting a "vein." Water obtained from till is generally of good quality for all uses, unless situated within the range of contamination from surface drainage. If the water once becomes polluted it may retain its dangerous character for a long time and for a considerable distance.

Water occurring in till is generally found within a few feet of the surface. As a rule it is not under pressure, however, and will not rise above the point at which it is encountered. The volume at any one time is not generally large, but there is a constant slow inflow. Water is abundant in a wet season or after a rain, but a large proportion of wells in till run dry in summer.

SAND AND GRAVEL.

Character and distribution.—Sand and gravel deposits are known collectively as "modified drift," for the reason that they are composed of till which has been reworked and assorted by water. Such deposits occurring in the form of flat or gently sloping plains are known as sand plains, deltas, or outwash deposits; those formed in long ridges on or under the ice are known as eskers; and those deposited as irregular hills near the ice front are known as kames or moraines. Many of these deposits are of great thickness. They all consist of pebbles and grains of sand, derived from a great variety of rocks.

Sands and gravels are widely distributed throughout the State. Moraine, kame, and esker deposits may occur in nearly all situations, though most commonly in the lowlands. Sand plains and outwash deposits are situated mostly along the valleys and lakes and within a few miles of the coast. Some of these plains are very extensive, covering many square miles of surface.

Relation to other deposits.—Most of these deposits overlie the principal body of till, although local beds of gravel are found underneath the till and in a few places gravelly layers occur in the till itself.

Gravel is also variable in its relations to clay deposits. Along the coast and in the valleys of Androscoggin, Kennebec, Penobscot, and other large rivers many extensive deposits of coarse gravels underlie

the clays, and in such places the upper surface of the gravel is likely to be undulating. In other places sand and gravel overlie the clay.

Water supplies.—Sands and gravels are very porous; in many of them 30 per cent of the volume is made up of free space between the grains. In such materials the whole mass is saturated below the water level, and when penetrated by wells copious supplies are quickly yielded. The waters are generally of good quality, and in Maine they contain less mineral matter than waters from most other types of deposits.

In passing downward through the sands surface waters are subjected to natural filtration and the substances with which they may have originally been polluted are frequently changed to harmless chemical compounds. In gravel and in the coarser types of sand the water moves more rapidly and the conditions are less favorable for filtration, so the waters may remain polluted. In general, however, waters from sands and gravels, if taken from a considerable distance below the surface, are safe to use. Plenty of water may generally be found at 10 to 20 feet, but supplies from greater depth are much safer.

In the sands and finer gravels the cheapest and best method of obtaining water is by driven wells, which can be sunk quickly and at very slight cost. In the very fine sands or quicksands, however, it is very difficult to exclude the material from the pipes, the quicksand frequently penetrating the well and clogging the pipe or ruining the pump. Because of the readiness with which sands and gravels yield their water, wells located close together frequently affect one another, some wells drawing water away from others. The ease of movement of the water is also the cause of great fluctuations in the level of the surface of the saturated zone, which falls rapidly after wet seasons. To procure permanent supplies the wells should penetrate to the level which the water surface occupies in the driest seasons.

CLAY.

Character and distribution.—The clay deposits of Maine differ greatly in composition and in origin. The most common type, however—a widespread formation of rather uniform character—is a light-gray or brownish, fine-grained, thin-bedded deposit, ranging from plastic to tough, but so dense as to be almost impervious to water. It is of marine origin, as shown by fossil shells which it contains in many places. In some localities there are thin layers of sand stratified with the clay. The thickness of this principal clay bed is generally not more than 20 to 30 feet, but in some of the deeper valleys and along the coast it may be as much as 100 feet.

Clay is widely scattered, but in general it occurs near the coast or in the valleys within 100 miles of it. Near the sea it occurs as

flat or gently sloping plains rising from 15 to 80 feet above tide. That these plains have been deposited in comparatively recent time is shown by their flat surface and the slight erosion they exhibit. Farther back from the coast, and in the valleys of Piscataqua, Saco, Presumpscot, Androscoggin, Kennebec, Penobscot, and other rivers, there are clays at higher levels, in some places above 200 feet, and in a few reaching 300 feet. The highest elevations are found in the Kennebec Valley, but in general the upper limit is little more than 200 feet. These high-level clays are best preserved in situations more or less protected from erosion, and when they occur in the main valleys they are much eroded, suggesting that they may be older than the coastal clays.

Relation to other deposits.—Where clay occurs it nearly always overlies the principal till deposit. In many localities, however, 3 to 5 feet or more of gravelly till rests on the clay. Gravel may overlie or underlie clay, or both. The clay is generally, but not invariably, unconformable with both the underlying and the overlying deposits.

Water supplies.—Clay is so impervious that in itself it contains little or no water which can be utilized as a source of supply. Water is frequently reported in clays, but it usually occurs in more or less sandy layers. In some places sand which approaches clay in fineness and which is sometimes mistaken for clay yields considerable water.

Clay is of greatest importance, not as a water bearer, but as a confining layer to porous sands, the water in which it prevents from escaping. In large areas it is overlain by sand which contains much water, resting on the impervious clay and moving slowly riverward or seaward.

The waters of clays, because of the fineness of the material, come into contact with relatively large amounts of mineral matter and frequently become mineralized, lime and salt being the most common substances dissolved. These waters are, as a rule, free from contamination. When, because of the absence of other sources, it is necessary to obtain supplies from clay, a well should be sunk with as large a diameter as practicable and be continued beneath the point at which the water is obtained to a sufficient depth to furnish ample storage capacity, as clay waters are slight in amount and are yielded very slowly. Dug wells are usually most satisfactory where the clay is near the surface, but such wells should be carefully covered and guarded from all sources of pollution.

OUTLINE OF GEOLOGIC HISTORY.

In order to make clear the relations of the various water-bearing and impervious formations of Maine a brief summary of the history of these formations is given. As a complete geologic investigation of

the State has never been made, little can be said regarding the rocks, but the sequence in which they were formed will be briefly reviewed.

The oldest formation in the southern part of the State is probably the Ellsworth schist,[a] of Cambrian age. Muddy sediments that subsequently became slates were deposited over large areas originally, but at the close of Ordovician time there was a long period of dynamic metamorphism in which these slates were turned on edge, cracked and broken, and intruded by molten granite, which now fills cracks in the slate and constitutes the surface over wide areas. The volcanic action may have extended into Devonian time. In some later age the trap dikes which penetrate the slate were formed by intrusion of a basic type of molten lava. Some slates, sandstones, and other rocks may have been formed after the intrusion of the dikes.

After the formation of all the solid rocks of Maine and their metamorphism and folding there were long ages during which few deposits were made in this part of the country, and the land was eroded into hills and valleys and brought into substantially its present relief. Then came the series of great glacial invasions which covered the State with a thick coating of drift. After the deposition of till and gravels and the retreat of the ice of the first invasion there was a long interglacial stage during which erosion removed the greater part of the glacial deposits, so that they are now found only in patches beneath the more recent till sheets.

The next glacial invasion of which we have any record is the one during which the greater part of the Maine bowlder clay was formed. During the subsequent disappearance of the ice coarse gravels were deposited in the valleys and along the coast, after which the widespread formation of marine clay took place. Later the land was elevated and the clay was deeply eroded. Still later the ice advanced again, depositing a few feet of a more gravelly type of till over some of the clay deposits. During the retreat of this final ice sheet immense deposits of sand and gravel were formed in most of the valleys and fresh marine clays were laid down along the coast. By subsequent uplift these clays have now reached an elevation of 20 to 80 feet above the sea, and form extensive plains in some localities.

RECOVERY OF UNDERGROUND WATER.

GENERAL STATEMENT.

Underground water can be obtained naturally, as it emerges from the ground in the form of springs, or artificially, by means of wells or collecting galleries. These methods and their bearing on the underground-water problems of Maine will be discussed separately.

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[a] The Ellsworth schist is described by G. O. Smith and E. S. Bastin in the Penobscot Bay folio (No. 149) of the Geologic Atlas of the United States, published by the United States Geological Survey.

SPRINGS.

Classification and emergence.—Wherever the water table or a water-bearing bed intercepts the surface of the ground a spring is formed. Springs are of various types. The waters may percolate through pores in the surface deposit or through passages in sand and clay, and these are known as seepage springs. They may traverse limestone or other soluble strata, dissolving passages for themselves, and finally emerge on a hillside, or they may flow out of fissures along joint cracks or fault or contact planes and be known as fissure springs. The term "fissure springs" is used rather comprehensively to include the springs issuing along bedding, joint, cleavage, or fault planes. The distinguishing feature is a break in the rocks along which the waters can pass, it being immaterial whether any considerable open space exists. Springs may occur in almost any topographic situation, even on a plain, but they are most common on steep hillsides.

The common method of classifying springs is by their predominating mineral constituents. Since the days of Aristotle many different classifications have been invented, and at the present time several are in use. The classification most commonly accepted in the United States is that of Peale,[a] who divides all mineral springs into two great groups—nonthermal or cold, and thermal—and into five classes with reference to chemical ingredients, viz, alkaline, alkaline-saline, saline, acid, and neutral or indifferent. Some writers use the term "chalybeate" for the fourth class instead of acid. This classification is easily subdivided, according to the predominant solid constituents of the water, which may be sodic, lithic, potassic, magnesic, salicic, iodic, bromic, arsenical, siliceous, manganic, aluminous, etc. The terms "nongaseous," "carbonated," and "sulphureted" designate the existence or nonexistence of gaseous contents.

The majority of mineral springs in Maine are either neutral or light alkaline-calcic or alkaline-chalybeate; only a few springs would fall in the other classes. They are not classified in this report, as the analyses (pp. 84–87) give a much better idea of their character.

Number and importance in Maine.—Springs are abundant in Maine, especially in the interior of the State. Very many are situated on hillsides, from which the water can be distributed by gravity to residences and farms. In places several families have combined and have distributed the water of the larger springs through their dwellings by pipes. Here and there the water is raised by windmills.

The water is very cool, temperatures as low as 45° being common and temperatures over 50° seldom reported. The spring waters are therefore valuable for dairy and creamery purposes.

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[a] Peale, A. C., Natural mineral waters of the United States: Fourteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1894, p. 66.

Springs are more generally utilized in those parts of the State where the well water is hard than where it is soft. In a few places, where the quality of water in the neighboring streams is poor, springs supply manufacturing establishments.

Information previously published.—The earliest publication regarding the mineral springs of Maine was made by Goodale in 1861.[a] The data contained in this report, consisting of a few analyses, temperatures, etc., were recompiled by Peale[b] in 1886. A few springs were described in 1899 by Crook.[c] Otherwise no information has been published regarding Maine springs except the reports of sales given in the Geological Survey's annual reports on the mineral resources of the United States.

Commercial springs.—A group of springs of great economic value to the State comprises those which are designated commercial springs, or those of which the waters are sold by measure. In this group there are two subclasses. The first includes springs that furnish table water to consumers in their vicinity at regular intervals. The second subclass comprises springs the waters of which are bottled and shipped to distant points, including the mineral springs whose waters are commonly supposed to possess medicinal properties, and also certain other springs the water of which is exceptionally pure. The sales of water from these two classes amount annually to more than $100,000, not including the sales of water from Poland Spring, the proprietors of which decline to make any statement as to the quantity or the value of the water supplied by them. It is believed, however, that the aggregate value of the water shipped from this spring is greater than that of the water from all the other springs in the State.

Altogether the springs reporting sales in southern Maine at the time this investigation was made (1906) were 44 in number, as follows:

Addison Mineral Spring, Addison, Washington County.
Arctic Spring, Bangor, Penobscot County.
Baker Puritan Spring, Old Orchard, York County.
Bluehill Mineral Spring, Bluehill, Hancock County.
Carrabasset Mineral Spring, Carrabasset, Franklin County.
Chapman's Spring, Brewer, Penobscot County.
Cold Bowling Spring, Steep Falls, Limington, York County.
Crystal Mineral Spring, Auburn, Androscoggin County.
Forest Spring, Litchfield, Kennebec County.
Glenrock Mineral Spring, Greene, Androscoggin County.
Glenwood Spring, St. Albans, Somerset County.
Highland Spring, Holden, Penobscot County.
Highland Mineral Spring, Lewiston, Androscoggin County.
Hillside Spring, Bangor, Penobscot County.
Indian Hermit Mineral Spring, Wells, York County.

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[a] Goodale, G. L., Report on the mineral waters of Maine: Sixth Ann. Rept. Maine Board of Agr., 1861.
[b] Peale, A. C., Mineral waters of the United States: Bull. U. S. Geol. Survey No. 32, 1886, pp. 13–16.
[c] Crook, J. K., Mineral waters of the United States and Canada.

Tehku Springs, West Hancock, Hancock County.
Katagodoc Spring, Eastbrook, Hancock County.
Keystone Mineral Spring, East Poland, Androscoggin County.
Knowlton's Soda Spring, South Strong, Franklin County.
Mount Desert Spring, Bar Harbor, Hancock County.
Mount Hartford Mineral Spring, Hartford, Oxford County.
Mount Oxford Spring, Sumner, Oxford County.
Mount Zircon Spring, Milton Plantation, Oxford County.
Oak Grove Spring, Brewer, Penobscot County.
Olde Yorke Spring, Old Orchard, York County.
Oxford Spring Home, Oxford, Oxford County.
Paradise Spring, Brunswick, Cumberland County.
Pepepsent Spring, Auburn, Androscoggin County.
Pine Spring, Topsham, Sagadahoc County.
Pine Grove Spring, Pittsfield, Somerset County.
Poland Spring, Poland, Androscoggin County.
Pownal Spring, New Gloucester, Cumberland County.
Pure Water Spring, Waterville, Kennebec County.
Raymond Spring, North Raymond, Cumberland County.
Rocky Hill Spring, Fairfield, Somerset County.
Sabattus Mineral Spring, Wales, Androscoggin County.
Seal Rock Spring, Saco, York County.
Sparkling Spring, Orrington, Penobscot County.
Switzer Spring, Prospect, Waldo County.
Thorndike Mineral Spring, Thorndike, Waldo County.
Ticonic Spring, Winslow, Kennebec County.
Underwood Spring, Falmouth Foreside, Cumberland County.
Wawa Lithia Spring, Ogunquit, York County.
White Sand Spring, Springvale, York County.

In addition to the springs given above, the following springs were reported by Peale,[a] with analyses that were made at various dates between 1861 and 1879. It is not known whether all these springs are still in use, but none of them report sales.

American Chalybeate Spring, South Auburn, Androscoggin County.
Auburn Mineral Spring, South Auburn, Androscoggin County.
Boothbay Medicinal Spring, East Boothbay, Lincoln County.
Ebeeme Spring.
Fryeburg Spring, Fryeburg, Oxford County.
Lake Auburn Mineral Spring, North Auburn, Androscoggin County.
Lubec Saline Springs, head of Lubec Bay, Washington County.
North Waterford Springs, northwest of Waterford village, Oxford County.
Poland Silica Springs, South Poland, Androscoggin County.
Rosicrucian Springs, Rosicrucian, Lincoln County.
Samoset Mineral Springs, Nobleboro, Lincoln County.
Scarboro Spring, Scarboro, Cumberland County.
Summit Mineral Spring, Harrison, Cumberland County.
West Bethel Spring, West Bethel station, Oxford County.

Analyses of some of the above were taken by Peale from Goodale's report.

[a] Op. cit., pp. 15-16.

Origin of spring waters.—A common belief regarding the origin of spring waters is that most of them are derived from a distant source. Several spring owners have told the writer, with perfectly truthful intent, that the water in their springs came from the White Mountains, at least 40 or 50 miles away. Owners of flowing wells in Islesboro have stated their belief that the water of the wells has its source in mountains on the coast, several miles distant.

In some regions springs may have such an origin. Many of the waters of mineral springs in the West come long distances underground. In Maine, however, it is not known that a single spring or well obtains its supply at a distance of more than a mile from the place where the water emerges. The majority of spring waters enter gravel deposits on the surface of a hill and pass downward along the top of the bed rock or "hardpan" deposits until they find an easy point of emergence on the slope. In a few mineral springs the waters issue from joint cracks or from fissures in rock. These waters may come from a considerable depth, but as their temperature is generally about the normal temperature of the region, they are not believed to come from a greater depth than 100 feet below the surface.

Curative properties of spring waters.—Most owners of commercial springs publish numerous testimonials of wonderful cures wrought by the waters. From some advertisements it would appear that the water would cure nearly every known disease. It is not within the province of this report to discuss the medicinal value of waters, but a word of caution should be given. There are many reliable spring companies whose waters are all that is claimed for them. There are other companies who claim manifold cures which have never been made. It would be folly to expect any natural water to be a cure-all; but a few spring waters may be valuable for curative properties, which depend on the presence of certain elements or compounds. A summary of the medicinal value of mineral waters is given in a recent bulletin of the Bureau of Chemistry.[a] Few of the Maine spring waters contain large amounts of dissolved solids, and therefore few can be called mineral waters in the true sense of the term. Most of them are merely pure natural waters, which are of value chiefly on account of the small amount of solid matter dissolved in them. It is by their purity and by their buoyant effect on the general health that they build up the system, rather than on account of any wonderful specific property inherent in the water.

[a] Haywood, J. K., Mineral waters of the United States: Bull. Bur. Chemistry, No. 91, U. S. Dept. Agr., 1905, pp. 12-16. Compiled from Crook's Mineral waters of the United States and Canada, Schweitzer's Mineral waters of Missouri, Cohen's System of physiologic therapeutics, and other publications.

COLLECTING GALLERIES AND TUNNELS.

In many places, where a large amount of water is needed, infiltration or collecting galleries are constructed, generally in flood plains of rivers, where the water which saturates the deposits can be collected and pumped out. This method is especially adapted to public supplies for fair-sized towns. It has not been used in Maine, but there are a number of communities where it could probably be used to advantage.

WELLS.

GENERAL TYPES.

Open wells.—Open wells are ordinarily used for domestic purposes throughout the State. Wells of this type are generally 3 to 6 feet in diameter and from 10 to 50 feet in depth, the most common depth being about 30 feet. The depth is dependent on the distance to the water table and on the character of the material penetrated. Such wells are dug by hand if in surface deposits, or blasted if in rock. Dug wells are curbed with stone or bricks, generally uncemented. Sometimes open wells under 2 feet in diameter are bored with an auger; such wells are curbed with wooden curbs. Open wells are adapted principally to localities where the water is near the surface, especially where it occurs in small seeps, in clayey materials, and requires extensive storage space. Open wells should never be situated near sources of pollution.

Tubular wells.—This term is used in a general sense to describe all types of wells cased with iron pipe, or drilled in solid rock where casing is not necessary. In diameter they vary from 1¼ inches in some shallow driven wells to 15 inches or more in the largest tubular wells sunk for city water supplies. In soft unconsolidated deposits of sand and gravel which carry considerable water at shallow depths small pipes 1¼ to 4 inches in diameter, provided with points and screens, may be driven by hand or power. Such tubular wells are termed driven wells. In localities where the upper soil contains polluting matter driven wells are much safer than open wells, for, when driven some distance below the water table, they draw only from the lower part of the reservoir. Shallow tubular wells may be bored, or in soft deposits they may be sunk by the "jet process," which consists in forcing water down a small iron "jet pipe" inside the casing, the water and drillings rising between the two pipes. The casing sinks by its own weight or is forced down. Such wells are generally 2 to 4 inches in diameter. Tubular wells in rock or other hard material are commonly "drilled wells," sunk by lifting and droping a heavy drill run by power. Tubular wells are cased with iron pipe in soft material and generally not cased in rock.

Connected wells.—Frequently two or more drilled wells are located near together and connected by exploding a charge of dynamite near

the bottom of the shallower one. Thus it is possible to pump several wells with a single pump. In a few places neighboring wells are connected naturally by joint cracks.

Combination wells.—A common form of well is the combination of dug and drilled or dug and driven well. Frequently when dug wells run dry the owner sinks a tubular well in the bottom, running the casing only to the bottom of the old open well, or only part way to the surface. As stated on page 54, such a combination well is unsafe.

METHODS OF OBTAINING WELL WATER.

Pumping.—In Maine there are few flowing wells, and in most wells the water must be raised artificially. The old-fashioned method of raising water is by the windlass, and in some parts of the State well sweeps are in common use. Such simple contrivances are only suitable for shallow open wells; in deep wells it is necessary to install a pump. This is also recommended in shallow wells, as it is easier of operation and the well can be covered to prevent entrance of animals, dust, organic matter, etc.

By far the great majority of wells in Maine are pumped by hand, and this method is in general fairly satisfactory when only a small

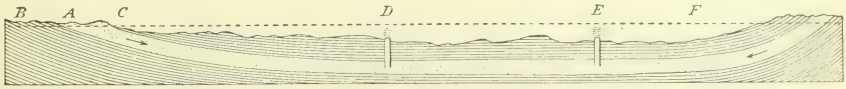


FIG. 3.—Diagram showing conditions under which flowing wells are commonly obtained in favorable regions. (After Chamberlin.) This sketch shows the contrast to conditions in Maine, illustrated in fig. 4. *A*, Porous stratum; *B*, *C*, impervious beds below and above *A*, acting as confining strata; *F*, height of water level in porous beds, or "head" of water; *D*, *E*, flowing wells supplied by water-filled bed *A*.

amount of water is required for domestic use. Hand pumps are either ordinary suction pumps, chain pumps, rotary pumps, or deep-well pumps. In the farming and summer-resort sections, however, windmills are common. They are inexpensive in comparison with the sums generally spent in drilling the well, and they save a great deal of manual labor, especially when the water is desired for stock. For public water supplies it is necessary to resort to some kind of power. Steam, hot air, and gasoline engines are in use. Many persons who own cottages on the coast or islands have these kinds of power, which give excellent service. There are in southern Maine about 30 wells pumped by steam, about 17 by gasoline engines, and about 20 by hot air. Several electric power pumps and two or three air lifts have been installed.

Artesian wells.—In many wells the water is under the pressure of a considerable head, forcing it to rise. Such wells are known as artesian wells. If the water rises enough to reach the surface, the wells are known as flowing artesian wells. The conditions under

which flows are normally obtained are described by Fuller,[a] and the cause of the flow is illustrated in fig. 3. The pressure is due to the confinement of the water in inclosed beds beneath an impervious layer. The water enters the porous beds where they outcrop on the surface and flows downward beneath the impervious covering. When the latter is pierced by the well the water rises in consequence of the pressure due to the superincumbent water. Only a few flows of this type occur in Maine, however, and these are generally from surface deposits in very local basins.

Bayley, in his notes on the underground waters of Maine,[b] gives the location of a few flowing wells in Maine, and several more were mentioned by Smith,[c] in his Kittery-York report. A few more have been found by the writer. Most of these belong to the type illustrated in fig. 4, where the pressure is derived from systems of joint

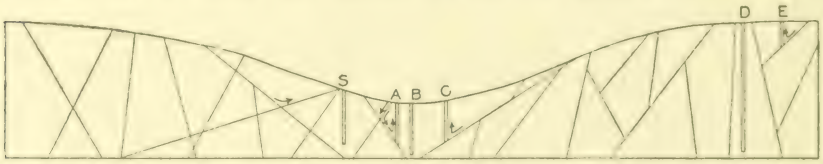


FIG. 4.—Diagram showing various conditions in drilled wells in Maine. *A*, *C*, conditions under which flowing wells may be obtained; *B*, *D*, *S*, conditions under which no water may be found; *E*, normal condition of obtaining water in drilled wells; *A*, conditions under which well may be polluted by surface drainage entering joint cracks near mouth of well.

cracks sloping from higher levels. A superficial coating of till or bowlder clay generally prevents the water from reaching the surface by springs at higher points on the hill. The water penetrates downward along joint cracks and is tapped by a well lower down on the slope or near the bottom of the valley.

In all, 34 flowing wells are known in southern Maine. These are distributed as follows:

Flowing wells in southern Maine.

Androscoggin County	2
Cumberland County	11
Hancock County	3
Knox County	1
Penobscot County	2
Sagadahoc County	2
Somerset County	1
Waldo County	4
Washington County	1
York County	7

It will be noticed that flowing wells are most abundant in the southwest corner of the State. In the town of Greenville, several miles north of the area considered in this report, there is a group of

[a] Fuller, M. L., Bull. U. S. Geol. Survey No. 319, 1908.
[b] Bayley, W. S., Water-Supply Paper U. S. Geol. Survey No. 114, 1905, p. 49.
[c] Smith, G. O., Water-Supply Paper U. S. Geol. Survey No. 145, 1905, pp. 122-123.

flowing wells which are better than any elsewhere in Maine. These will be described in the forthcoming report on the underground waters of northern Maine. The highest flow due to artesian pressure in southern Maine is about 5 feet above the surface. In one well at Greenville, however, the water rises 20 feet above the surface.

LOCATION OF WELLS.[a]

Factors to be considered.—The chief factors to be considered in choosing the best location for a well are (1) position of the water table, (2) accessibility and convenience, (3) direction of movement of ground water, (4) direction and movement of sewage, (5) points of most abundant water, and (6) possible sources of pollution.

Position of the water table.—The first factor is generally not important except in open or driven wells. These are generally shallow, because of the nature of their construction, and their cost is small. "On passing downward in porous or semiporous materials, such as those in which most open wells are located, a level is soon reached below which the ground is saturated with water (at least down to the first impervious stratum). This water body, or ground water, as it is called, has a definite upper surface, known as the water table, which conforms in general with the broader surface irregularities, but with the difference that the surface of the water table is flatter than that of the ground, being far below the ground on hilltops and cutting the surface in valleys." At a stream or swamp the water table reaches the surface, and the nearer to such natural features the well is situated the less will be its cost. The places where the water table is nearest the surface, however, are the most subject to pollution, and cheapness is often gained at the expense of safety.

Accessibility and convenience.—The location of any well is necessarily determined to a large extent by its nearness to the place where the water is to be used. Convenience often demands that open wells should be situated under houses or in barnyards, near privies or cesspools, or in other situations where they are subject to pollution, but it is always better to locate the well a few hundred feet away than to take such a risk.

Points of most abundant water.—In many places, especially on the uplands covered with bowlder clay, it is necessary to choose the location of open wells with reference to the relative abundance of water. In bowlder-clay deposits the best situation can not always be told in advance, as water in them occurs most commonly in somewhat porous channels not visible from the surface. When there is a choice between digging in bowlder clay or in gravel the latter should be chosen, especially if the gravel is underlain by bowlder clay, as

[a] Considerable portions of this and the succeeding section are taken by permission from unpublished notes of M. L. Fuller. Literal excerpts are inclosed in quotation marks.

the water will penetrate downward until stopped by the more impervious bed, and will then be held in a sort of reservoir until tapped by a well or drained off laterally. On slopes the most abundant water is near the base of the slope. Generally there is abundant water in valley drift, but on the hills it occurs in smaller quantities.

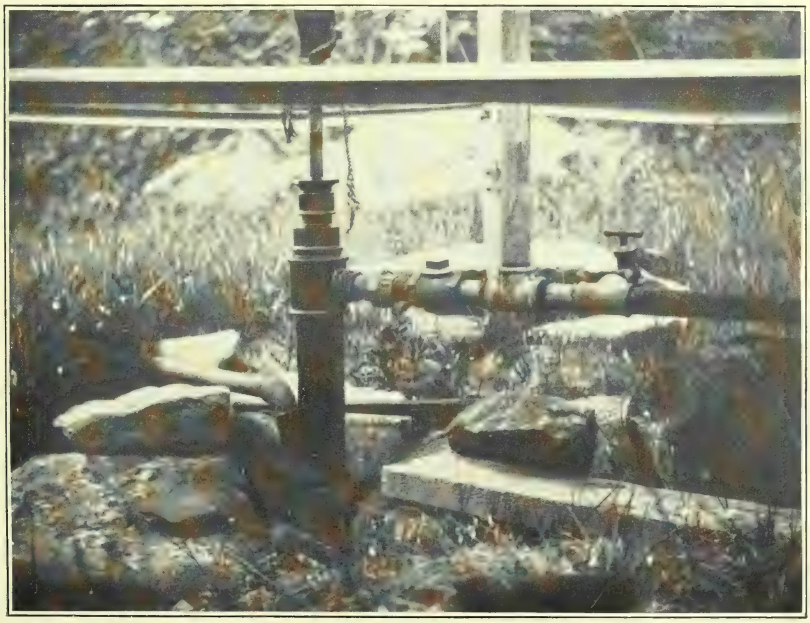
Direction of movement of ground water. "The motion of ground water is always in the direction of steepest slope of the water table, and as this is likely to correspond with the direction of the surface slope the direction of motion of the ground water generally approximates that of the surface drainage." In drift deposits water moves from higher to lower levels. On hills it will move downward through the drift, along the top of the underlying rock. Exceptions are where till, clay, rock, or other relatively impervious formations dip in the opposite direction from the surface. In such cases the water will move downward from the surface along the top of the impervious bed. Wells which are intended to tap the reservoir of ground water should be situated at points toward which the water is moving, and these points must be determined by a study of the surrounding formations.

Sources of possible pollution.—Next to the question of abundance of water that of pollution is most important in a consideration of the location of wells. Purity or impurity of underground water is dependent on several factors. If porous drift extends downward indefinitely from the surface, opportunity is afforded for the downward penetration of polluting substances, but the water may sometimes be purified by filtering through sand. If the water-bearing bed is overlain by a covering of impervious rock or clay it is protected from pollution. The purity of water, even in deep wells, may be dependent on the tightness of the casing, both at the joints and at the connection with the pump. Some deep wells in Maine have been rendered dangerous by leaving the casing open at the top, thus affording entrance for surface drainage, small animals, etc. (See Pl. IX, *B*.) When wells are drilled into rock it is customary to drive the casing through the drift and a few feet into the ledge for the sake of protection, but where poor connection with the rock is made contamination often results. The purity of water is also dependent on the depth and kind of casing, as is explained on page 66.

"No well should be located where polluting matter has access to it. Such matter usually comes from cesspools or privies, slops thrown on the surface, backings from hen yards, pigpens, and barnyards, from manured fields, animals falling into the water, and filth thrown in through the open top or washed in through the plank coverings or leaky casings. The matter entering through the top can be kept out by cement, iron, or other impervious curbings. The entrance of material at the bottom of shallow wells can be prevented only

A. WELL AT COUNTY JAIL, WISCASSET.

Showing best method of protection from surface drainage.



B. WELL AT HERON ISLAND, SHOWING OPEN CASING.

PROTECTED AND UNPROTECTED WELLS.

by locating them beyond the reach of contamination. Where any of the polluting agents are present care should be taken to see that the well is located at least 100 feet away and on distinctly higher ground, so that both the surface drainage and the underground drainage—which generally moves in the same direction—will be away from it. On flat sands the wells should be at least 150 feet from any source of pollution. The importance of choosing a location safe from polluting influences is almost universally underestimated. Laying aside considerations of comfort and health, a safe well is nearly always, in the long run, the cheapest. Safety should invariably be made the first consideration instead of the last."

Location of deep wells.—The chief consideration in locating deep wells is to obtain a supply, slight differences in location seldom greatly affecting cost; moreover, owing to the prevailing use of casing in soft deposits, safety from ordinary pollution is insured. The occurrence of deep waters depends on the character and structure of the rocks far below the surface, and the well may usually be located independently of surface relief. In crystalline rocks and highly folded slates, such as are found in Maine, it is impossible to predict with certainty where a well should be drilled in order to be successful, although a study of the rocks by a geologist should afford some information regarding the probability of obtaining successful wells in various situations.

CHOICE OF A TYPE OF WELL.[a]

Factors to be considered.—"The type of well is the first and perhaps the most important point to be decided when sinking for water is contemplated. Of the many types in use, including bored and driven wells, those sunk by the jet process, and those drilled by a rotary or percussion rig, each possesses one or more points especially qualifying it for use in some of the varying conditions encountered in drilling; on the other hand, each has some disadvantage which may disqualify it for use under certain circumstances. The chief factors which govern the selection of a type are usually the amount of water needed, the character of the materials to be penetrated, the depth to which the well must be sunk, the cost of sinking, and the safety of the resulting supply."

Amount of water obtained by different types.—Where the amount of water entering the well is small, it is obviously a distinct advantage to have a well of sufficient size to store water during the times when it is not in use. Open wells are best for this purpose, and this type also has the advantage of cutting a larger cross section

[a] Considerable portions of this section are taken by permission from unpublished notes of M. L. Fuller.

of the water-bearing bed, and thus intercepting more water. In sands and other soft porous materials, which contain considerable water at slight depths, a driven well is desirable. Where water occurs in joint cracks, as in granite and slate, a well of large diameter offers greater chance of striking a seam of water than a well of small diameter. For all deep wells and for shallow wells in all but the softest materials drilled wells are recommended, as they are cheaper, more quickly put down, and safer than wells of the old-fashioned types.

Safety of different types.—Polluting matter finds entrance to a well in a number of ways. In dug wells it may enter through the crevices in the stone, brick, or wood curbing, or even through the pores of the brick itself; in bored wells it may enter through the uncemented joints of the tiling or cracks between the staves of the wooden curbing; and in drilled or driven wells it may enter through leaky joints or holes eaten in the iron casing by corrosive waters. In all types of open and curbed wells there is particular danger of surface wash. Open wells can be protected from this danger by proper curbing, but shallow wells of all kinds can be protected from underground pollution only by safe location. In a town or village, and even in close proximity to a farmhouse, few locations are safe, and hence drilled wells are almost universally the most desirable. These wells may become dangerous through leaky joints in a casing, through poor connection with the bed rock, through corroded casings, and through open tops. Where tiling is used for casing it may become so broken as to render the well dangerous. The danger of pollution in drilled wells can be remedied by proper construction.

"A particularly dangerous type of well—the more so because it is fancied to be secure—is a combination of the dug and drilled types. Because of the slight saving in expense, drilled wells are frequently sunk in the bottom of old dug wells, the casing often beginning at the bottom of the latter. Although the water encountered by the deep well may be perfectly pure at the start, contamination may take place almost immediately by the entrance, especially after rains, of seepage water into the open well and thence into the casing of the drilled well. The remedies are obvious. Either the casing should be carried to the surface of the outside ground, or at least above the highest level ever reached by the water, or the open well should be converted into a water-tight system by the application of a thick coating of cement over both sides and bottom."

Types in use in Maine.—In this State dug wells greatly predominate in number over wells of all other types. Such wells are, however, relatively shallow; few of them exceed 50 feet in depth. For that reason few dug wells are listed in Professor Bayley's table

(pp. 242–259). Next to dug wells the most numerous are those sunk with an ordinary churn drill. Most of the wells described in this report are of this type, as they are by far the most practicable in regions of hard rock. Driven wells are abundant in Maine, but are of necessity confined to shallow depths and to valleys in which the sand and gravel deposits are very soft and easily penetrated by the well point. On account of their shallowness few of them are included in the table mentioned. There are very few bored wells in Maine, and these are all rather shallow.

DEPTH OF WELL.

OBJECT OF DEEP WELLS.

The depth to which a well is to be sunk is one of the chief questions to be decided, for on the depth are dependent both the type and the location. There may be at least three reasons why an owner should sink a deep well instead of a shallow one, viz, (1) to obtain an adequate supply, (2) to get a higher head, and (3) to get purer water.

RELATION OF ADEQUATE SUPPLIES TO DEPTH OF WELL.

Erroneous beliefs.—There seems to be a general belief that the amount of water increases with the depth, and that water may be found anywhere if only the well be drilled deep enough. Nothing, however, could be much farther from the truth. In surface deposits it is true that more water may be found with increasing depth as far as the gravel extends, but in the bed rock the occurrence of water follows different laws. The greater part of the water found in the earth came originally in the form of rain, and, as would be expected, the amount of water actually decreases rather than increases with great depth. Many rocks encountered by deep mines and wells, especially at depths below 1,000 feet, are entirely devoid of water.[a]

Limiting depth of abundant water.—In an investigation of underground waters in crystalline rocks in Connecticut it was found that, although down to a depth of 200 feet the chances of striking water by deeper drilling are good, below 200 feet the chances decrease. The difference is due to the closeness of the joint cracks below that depth.[b] Substantially the same conclusion has been reached for many rocks in Maine. Several wells more than 500 feet in depth, drilled in granite and gneiss, have obtained practically no water. One of the most experienced well drillers in Maine states that the

[a] Fuller, M. L., Total amount of free water in the earth's crust: Water-Supply Paper U. S. Geol. Survey No. 160, 1906, pp. 64–70.

[b] Ellis, E. E., Occurrence of water in crystalline rocks: Water-Supply Paper U. S. Geol. Survey No. 160, 1906, pp. 22–23.

average depth to which it is desirable to drill in granite is 185 feet, below which the chances decrease.

In many of the slate areas of the State, on the other hand, the maximum desirable depth seems not to have been reached, as wells 300 and even 400 feet deep report increasing supplies with increasing depth. As few slate wells more than 400 feet deep have been drilled, no statement can be made for greater depths, but it is believed that the cracks tend to close below 600 feet. As the occurrence of water in this State is uncertain the depth at which wells strike a sufficient volume of water is extremely variable and can not be predicted.

Conditions of greater abundance at depths.—It is true that under certain conditions the volume of water found may increase with the depth. Sand, gravel, and bowlder clay, for instance, are dry down to the level of the water table, but below this level the amount of water increases until rock or some other impervious bed is reached. In some parts of Maine the surface deposit is clay, which contains very little water, but when this is penetrated gravels that contain an abundance of water are frequently found. Again, in rocks where the joints are open to great depths water may descend several hundred feet. Such is the case in some of the slate areas of Maine, where the deeper wells are the best.

Conditions of greater abundance near surface.—On the other hand, the quantity of water held in thick sand and gravel deposits is generally more than that in the rock or till below them. Water is more abundant in valley deposits than it is in the underlying rock. Where water-bearing sand rests upon clay the amount of water generally decreases as the clay is entered. Investigations have shown that in most rock wells the joint cracks are likely to be open near the surface and to diminish in size with increasing depth, and that if a depth of 200 to 500 feet or so, differing with the kind of rock, is reached without striking water it is generally cheaper and more satisfactory in all respects to start a new well. Usually the greater abundance of water in deep wells than in shallow ones is due to the fact that a greater number of water-bearing seams are encountered, and for this reason it is advisable to drill at least 200 feet if a sufficient supply is not obtained nearer the surface.

RELATION OF HEAD TO DEPTH OF WELL.

There is a general belief that the head as well as the volume increases with increase of depth. In a few wells such an increase was noted, for example, in the flowing wells at Greenville and in scattered wells elsewhere; but such cases are rare and are always due to chance local conditions which do not prevail over any wide area. In Maine flowing wells are exceptional and should not be hoped for. Sometimes the level of water in the well is raised by

going deeper, but this too is an accident. Most wells are drilled a few feet deeper than the water vein in order to form a reservoir for the water and whatever sediment it may contain.

RELATION OF PURITY OF WATER TO DEPTH OF WELL.

The prevailing idea in regard to purity, as in regard to volume and head, is that deep waters are best. This is generally true, for the reason that shallow waters are usually in unconsolidated deposits, and not being protected by impervious rocks or clay they are more likely to be polluted by surface drainage. A deep rock well is nearly always to be recommended where pure drinking water is desired.

When water is needed for industrial purposes the problem is somewhat different. While water from a depth is generally free from surface pollution, it often contains considerably more mineral matter in the form of incrusting constituents and is generally harder than most surface waters. In Maine, however, few waters are so hard as to prevent their use for laundries and boilers.

DEPTH OF WELLS IN SOUTHERN MAINE.

In the region covered by this report the drilled wells range in depth from 20 to more than 800 feet. Only a few, however, are more than 500 feet deep. Out of 500 wells in Professor Bayley's list (see pp. 242–259) which are more than 50 feet deep only six exceed 500 feet. In order to show the common depth of wells in various parts of southern Maine the following table has been prepared. Only drilled wells more than 50 feet deep are here considered.

Number of wells of different depths in southern Maine.

County.	Between 50 and 100 feet.	Between 100 and 200 feet.	Between 200 and 300 feet.	Between 300 and 400 feet.	Between 400 and 500 feet.	More than 500 feet.	Total number reported more than 50 feet.
Androscoggin	5	4	1			1	11
Cumberland	44	30	22	5		2	103
Franklin	2						2
Hancock	47	15	6	1	1	1	71
Kennebec	16	15	3	1		1	38
Knox	7	15	7	3		1	33
Lincoln	31	20	2	1			54
Oxford	4	4					8
Penobscot	39	13	4	1	1		58
Somerset	5	1					6
Waldo	26	19	10	4			59
Washington	8	2		1	1		12
York	29	9	3	2			45
	263	147	58	19	3	6	500

DEPTH TO PRINCIPAL WATER SUPPLY.

In parts of the country where water occurs in definite beds it is possible to predict the depth at which it will be found by calculation

from knowledge of the lay of the rocks and the altitude of the surface. In Maine, however, the water occurs at no definite depth, and all statements as to the distance below the surface at which it will be found must be expressed only as probabilities. Professor Bayley, in compiling the well records, made an effort to obtain figures giving the depth of the principal water supply below the well mouth. It was possible to obtain these figures for more than half the wells; in the rest the depth to the water vein was not known by the owners.

In order to make comparison of the depths at which the principal supply was found in various parts of the State the following table has been prepared, giving the depths of the principal water bed as found in the several counties:

Number of wells in southern Maine obtaining principal water supply at stated depths.

County.	Between surface and 50 feet.	Between 50 and 100 feet.	Between 100 and 200 feet.	Between 200 and 300 feet.	Between 300 and 400 feet.	Below 400 feet.	Total number reported.
Androscoggin	1	3	1				5
Cumberland	6	19	14	9		1	49
Franklin		1					1
Hancock	11	35	7	1		1	55
Kennebec	4	7	6	1	1		19
Knox	1	10	11	1			23
Lincoln	6	20	8				34
Oxford	2	2					4
Penobscot	11	22	2	3		1	39
Sagadahoc	1	7	1	2			11
Somerset		2					2
Waldo	10	10	6	7	3		36
Washington	1	2			1		4
York	3	12	5	2	1		23
	57	152	61	26	6	3	305

By reference to the table it will be seen that nearly three times as many wells drilled more than 50 feet obtain their principal vein of water between 50 and 100 feet from the surface as those which obtain it within 50 feet of the surface. More wells obtain water between 100 and 200 feet than obtain it within 50 feet of the surface. The number encountering their principal water vein deeper than 200 feet, however, diminishes rapidly with each 100 feet of depth. Hence it can be said that the principal water vein may in the greater number of wells be looked for between 50 and 100 feet below the surface; but no one prospecting for water should begin to get discouraged unless he drills more than 200 feet without finding water.

Several exceptions can be made to the statements regarding the occurrence of the greatest number of water seams between 50 and 100 feet from the surface. For instance, it will be noticed that in Waldo County as many wells obtain water at depths less than 50 feet as between 50 and 100 feet, but that at the same time an equal number

obtain their largest supplies between 200 and 400 feet from the surface. Waldo County is largely made up of slate, which seems to hold plenty of water, and in that section the principal supply is just as likely as not to be obtained at depths greater than elsewhere. The statement is believed to hold true for Penobscot County also, although in that county shallow wells have met with such success that few have been drilled much below 100 feet. A further discussion of the probable maximum depth of water is given under the descriptions of the different rocks. (See pp. 29–38.)

DIAMETER OF WELL.

By far the most common diameter for drilled wells in this part of the country is 6 inches. Most drillers prefer to sink 6-inch holes, and the prices which they quote and those given in this report are for this size. For domestic use a sufficient supply of water can generally be obtained from a 6-inch well, and it does not seem desirable, except in particular cases, to go to the additional expense of sinking an 8-inch or 10-inch well. A 4-inch well is likely to be too small to give satisfaction, but a few of that diameter have been drilled.

Where a larger amount of water is needed, as in creameries, factories, hotels, etc., an 8-inch well is frequently sunk. Most of the wells drilled for the United States Government at forts along the coast are 8 inches in diameter, although a few of them are 6 inches. For a number of city water supplies, large hotels, etc., 10-inch or 12-inch wells have been drilled. These are expensive and ordinarily not desirable. Although theoretically they will yield a larger volume of water, it is not supposed that the amount of water stored in rocks in this State is sufficient to warrant many wells of this size. It is generally preferable to sink two or more smaller wells. In the early days of well drilling in Maine the business was not such an established one, and the wells were generally of odd sizes. For that reason many wells of 5-inch, 7-inch, 9-inch, and other diameters are reported.

Driven wells sunk for domestic purposes are generally from 1¼ to 2½ inches in diameter, and this size suffices for most purposes. Larger wells are sometimes driven, however. In some of the city waterworks batteries of 30 or more 2½-inch driven wells are used.

UNCERTAINTY OF RESULTS.[a]

"The discovery of water by a given well in rocks of this State does not necessarily indicate that other wells drilled in the same neighborhood will likewise yield water. As a matter of fact, in several places dry wells and fairly successful wells are situated side by side. At North Haven, in Penobscot Bay, a well was drilled to a depth of 300

[a] The three paragraphs within quotation marks are from notes of Prof. W. S. Bayley.

feet without finding water; while a second well, less than 50 feet distant, encountered water at 60 feet under sufficient pressure to raise it within 14 feet of the surface. This well yields about 350 gallons a day.

"Again, at Palmyra, in Somerset County, three wells were drilled in slate. One was dry to a depth of 157 feet, at which depth the well was abandoned. A second, 70 feet distant, was drilled 80 feet, when it suddenly filled within 4 feet of the surface. It yields, however, but 25 to 50 gallons daily. A third well, 170 feet from the second one, struck water at 60 feet and now yields about 200 gallons daily.

"In the Kittery-York district a well on the road between York Harbor and York Beach yields 100 gallons an hour, the water vein at a depth of 25 feet giving a pressure sufficient to drive the water 2 feet above the surface. Near by, on Cape Neddick, only a few hundred yards from the flowing well, is another that was drilled to a considerable depth without encountering any water. A third well, at a slightly greater distance from the first, was drilled 87 feet, at which depth salt water was struck."

Fortunately, however, the risk of missing water is not great. The number of dry wells reported is small. The rocks in the southern part of the State (where most of the drilled wells are situated) are nearly all slaty, schistose, and much jointed rocks cut by granite and other igneous rocks. The foliation planes and joint cracks are numerous and closely spaced, so that a drill hole of even moderate length can scarcely avoid intersecting many of them. They afford abundant space for the storage of large quantities of water, but they yield it comparatively slowly.

An important consequence of the manner of storage of water in schistose and jointed rocks is that prophecies regarding the depth at which the water is to be found are valueless. In a gently folded region like Minnesota or Kansas an approximate estimate of the position of the porous water-bearing bed is usually possible. In areas of crystalline or metamorphic rocks like Maine, on the other hand, each well is an independent problem. The hole is sunk until it strikes a crevice or a group of crevices yielding sufficient water for the purpose needed, and the depth to which it must be sunk can not be foretold. In some wells water is encountered within 50 feet of the surface; in others only at much greater depths.

PROPORTION OF SUCCESSFUL WELLS.

An earnest effort has been made to obtain accurate information regarding the proportion of wells drilled which are successful. Such an estimate is difficult to obtain for several reasons. In the first place, most well drillers are naturally inclined to be optimistic and report few if any failures. Second, real failures are likely to be for-

gotten by residents of a community, and it is hard to get track of them. Third, there is no agreement between underground-water experts, well drillers, and owners as to what really constitutes a successful well. In several instances the United States Government has been known to abandon a well for the reason that its supply was only 10 to 20 gallons a minute. Large hotels have abandoned wells for the same reason. For ordinary domestic purposes, however, a well with this capacity is called very successful, and even 1 or 2 gallons a minute will usually suffice for a single family. If less water than this is obtained, the well is generally ranked as a failure.

As stated above, most well drillers report no failures. A few of the most experienced drillers report one or two wells in a hundred that do not yield sufficient water. In many instances there is a disagreement between the driller and the owner, owing to the fact that the well produced a fair amount of water when the vein was first pierced, but by the time the bill had been paid and the driller had moved to some other town the water gave out. Cases like this are due to the water occurring in pockets. For this reason some of the more experienced and reliable drillers will not leave a well until after waiting a sufficient time to determine whether the supply is likely to be permanent.

In the following table a successful well is considered as one that supplies enough water for ordinary domestic use, generally a gallon a minute. In compiling the table all wells more than 50 feet in depth in which the type of rock was known were considered. The unsuccessful wells include both those in which little water was found and those in which the water was of very inferior quality.

Proportion of successful wells in southern Maine.

Type of rock.	Number of successful wells.	Number of unsuccessful wells.	Total number of wells considered.	Percentage successful.
Granite	51	8	59	86
Gneiss	12	2	14	86
Slate	191	[a] 23	214	88
Schist	34	3	37	92
Trap and greenstone	10	3	13	77
Complex	42	[b] 6	48	87
	340	45	385	88

[a] Including six wells ruined by entrance of sea water.
[b] Including one well ruined by entrance of sea water.

It will be seen that, aside from the trap and greenstone wells, the percentage of successful wells was from 86 to 92, the average being 88. On account of the factors mentioned in the preceding paragraph, however, this is possibly somewhat overestimated. It is evident that trap and greenstone are the poorest rocks in this State in which to drill. If the six slate wells ruined by salt water should be included

with the successful wells, the percentage of probable success by drilling in slate would become 93, agreeing very well with the percentage for schist.

CAPACITY OF WELLS.

As very few wells in Maine are pumped by power, and as fewer of these are operated continuously or more than several hours at a time, it is difficult to make any definite generalization regarding the amount of water which they will yield. The best that can be done is to state the maximum and minimum amounts obtained and the most common reports of the yield in gallons a minute. Some of these reports are based on only a few minutes' pumping; in other cases the wells have been operated as a test for several hours or days continuously. Probably the majority of wells in Maine yield less than 5 gallons of water a minute. There are, however, many reports of yields as high as 10 or 20 gallons a minute, and a number of wells where more than 50 gallons a minute have been obtained for several hours continuously. A few yields of 100 to 200 gallons a minute are reported, but such high amounts can not be vouched for, as the exact conditions under which the test was made are unknown. One of the greatest factors in the reported capacity of the well is obviously the capacity of the pump used.

INCREASE IN YIELD.

In some wells the capacity increases with age. This is due to the fact that a newly drilled well contains at its bottom much fine material derived from the drilling, which tends to clog up the pores and water veins in the rock. As time passes this material is washed out, and the yield of the well becomes larger. Instances of such increases in yield are the well of the Penobscot Coal and Wharf Company at Searsport, that of the Maine Insane Hospital at Widows Island, and some wells in the town of Standish. In one well in Standish, drilled ten years ago, not more than half a gallon a minute could be obtained at first, but it has now increased in yield so that it can not be pumped dry.

DECREASE IN YIELD.

It is not uncommon for wells to decrease in yield some time after they are drilled. The change may begin to take place shortly after the well is first used, or it may not begin for years. In the former case it is generally due to the fact that pockets of water were struck, rather than permanent veins. In the latter case it may be due to several causes. Sometimes, when a drilled well is supplied largely by surface water, a single dry season will have a great effect on its yield. Some shallow drilled wells vary greatly according to the month of the year, but the best deep wells are supplied from sources

which can not be affected by changes in a single season, though sometimes a series of years in which the rainfall is below normal will affect these wells. In other wells the decrease in volume of water may be due simply to the gradual draining of the subterranean reservoir, and some such wells may never recover their original capacity. Usually when a newly drilled well has been carefully tested by the drillers and reported to yield several gallons of water a minute, and this capacity continues for several days, it is safe to regard the well as a success. It is never wise to let the driller depart until it is reasonably certain that the water does not come from pockets.

INTEREFFECT OF WELLS.

An interesting study could be made of the effect of neighboring wells upon one another, and such a study would be of great benefit to the inhabitants of a region and would increase the knowledge of conditions under which underground waters occur. The well at Foster's dyehouse at Portland is 140 feet deep in slate, and several water beds were penetrated. When a second well was drilled about 600 feet distant the water level in the dyehouse well was depressed about 3 feet.

In J. C. Rogers's granite quarry near Stonington two wells were drilled to depths of 94 and 279 feet. These wells are naturally connected by a joint crack about 60 feet from the surface. By pumping the 94-foot well water can be drawn from both. The capacity is 60 gallons a minute. The wells of the Southwest Harbor Water Company are situated 36 feet apart and are connected 90 feet from the surface.

At Dark Harbor, in the town of Islesboro, Charles Pendelton sunk a well to a depth of 88 feet. At a later date a well was sunk 16 feet distant, on the Allen property, and in half an hour from the time water was struck in the Allen well the yield of the Pendelton well diminished to such an extent that it would pump down so as to suck air. The Pendelton well was then deepened to 140 feet and encountered a large volume of water which supplied both wells. Water will now rise within 5 feet of the surface in both, but the greater part of the water in Allen's well is supplied from Pendelton's. The rock is much broken up at this place, and in the Pendelton well the drill was very nearly lost in a crack at a depth of about 80 feet.

USES OF UNDERGROUND WATER.

The prevailing use of both well and spring waters in Maine is for drinking and other domestic purposes and for watering stock. Spring and well waters are used for the public supplies of many villages, and well water is used in boilers of locomotives or manufacturing estab-

liniments, there being little water in Maine that gives too much scale for this purpose. Several creameries use water for cooling cream, and pulp mills use it for cooling acid. In granite quarries, especially on the islands, the water problem is an important one, and in several places well drilling has met with success. In addition to the ordinary uses of water, certain spring waters have value as "mineral waters." They are put on the market and shipped to distant centers, or the springs are made sites for summer hotels, thus contributing to the health of the country and to the wealth of the State.

COST OF WELL DRILLING.

The cost is necessarily an important factor in the sinking of wells. It varies with the locality, the kind of rock, and other conditions. For a rock well under 30 feet in depth the cost of drilled and open wells is about the same. A shallow well in drift may be cheaper if dug than if drilled, but in general drilled wells are the cheapest if they are carried down more than a few feet. Of all types the cheapest is the driven well, and this type is recommended wherever practicable. Such wells can be sunk to moderate depths through sand, fine gravel, and clay for $10 to $20.

The cost of drilled wells is very variable, depending on the locality and the kind of rock. In Aroostook County, where the rocks are rather soft slate, the cost is only $2 a foot in surface deposits and $1 in ledge, cased to rock and the casing furnished. Near Bangor, where the rock is slate, the charge is $3 per foot for the first 50 feet, $4 for the second 50 feet, and $5 for every foot below 100. This price includes the casing. A well 247 feet deep at Bangor cost $940; the windmill cost $66 and the pump $45. At other places in Penobscot County the price is $3 a foot straight, and in some towns it is less. In Lincoln County, in the area of complex, the common charge is $3.50 a foot, but some wells have been drilled for less. On account of the expense of drilling, it is possible that the price in this section may be raised. At Bucksport, in Hancock County, a well 308 feet in depth cost $1,540 and a steam pumping plant cost $360.

Wells on the islands cost more than those on the mainland. In Lincoln County island wells cost $6 a foot. In Hancock County, where the rock is largely granite, the cost is generally $4 on the mainland and $5 on the islands. Most drillers charge $6 in granite. Blasted wells, only a few feet deep, are $4 a foot. On Widows Island, near North Haven, a well 109 feet deep cost $525; and a gasoline engine and pump $177. In Islesboro, where more drilling has been done than in any town in Maine, the charge is $3 a foot, but drillers will not set up their machines without an agreement to drill at least 50 feet.

In Washington County, where little drilling has been done, the cost is $6 a foot. At Portland and vicintiy it is $4 a foot in drift and

$4 to $6 in rock. A 151-foot well on Cape Elizabeth cost $752, the pump $246, and a 40,000-gallon tank $900. A well 120 feet deep on Peaks Island cost $450 and a hot-air engine and deep-well pump $400. On Diamond Island a 96-foot well cost $500. In York County the price is generally about $6 a foot. In the vicinity of Winthrop, Kennebec County, where the rock is slate, the price has been raised from $3 to $5 a foot. The lower price ought to be sufficient here, as it is in most of the slate areas.

NOTES ON WELL DRILLING IN MAINE.

GENERAL STATEMENT.

As drilled wells are becoming more and more necessary in Maine, and as well drilling constitutes a considerable industry, which benefits the community at large, it seems important to include here a brief discussion of certain aspects of drilling that are not understood or appreciated by everyone.

RELATION TO KIND OF ROCK.

Speed of drilling.—The speed of drilling in Maine varies from a few inches to 30 feet a day, depending on the kind of machine, character of rock, abundance of joint cracks, etc.

With a good machine an experienced man can drill a 6-inch hole an average distance of 5 feet a day. In granite, however, 5 feet is usually the maximum daily performance, and sometimes a very hard, fine-grained phase of the rock is struck in which the drill will not go more than 1 foot a day. These hard portions of the rock are generally aplite dikes. In the slates of southern Maine the speed of drilling varies with the nature of the rock, ranging as a rule from 2 to 14 feet a day, though in southern Aroostook County, where the slate is softer, it averages 20 feet. One driller claims to have sunk a slate well 44 feet deep in eight hours, but this record is exceptional. Quartz seams in slate retard the speed of the drill.

A well on House Island, near Portland, drilled in metamorphic slate or schist, is said to have been deepened 35 feet in one night. In the 196-foot well of the Warren Water Company the average speed was 3 feet and the fastest 9 feet a day. As a rule, the finer the grain of the rock the harder it is to drill. In schist and metamorphic slates the drilling is much slower where they stand on edge than where they are flat. Pl. X, *B*, shows a dike of granite in slate, illustrating how differences in type of rock may affect the speed of drilling.

Effect of joint cracks.—Where joint cracks are parallel to the surface, or nearly so, they seldom affect the ease of drilling. Where they dip at a high angle, especially in the harder rocks, drilling becomes less easy. Frequently tools become stuck in the rock and

much time and labor are wasted in recovering them. At other times the bit will strike the hard, smooth surface of the rock and glance off to one side, making a crooked hole. In such cases stones and occasionally scraps of soft iron are thrown into the hole and blasted with dynamite, breaking up the rock so as to give the drill a hold on it. Sometimes it is necessary to abandon such wells and make a second attempt. The slates of Penobscot County have few troublesome joints, and in them drilling is relatively easy. Most of the crooked holes have been sunk by inexperienced drillers. In some wells in granite and other hard rock the drilling is reported to "sharpen the drill." Other types of rocks cut the drill to pieces.

CASING FOR DRILLED WELLS.

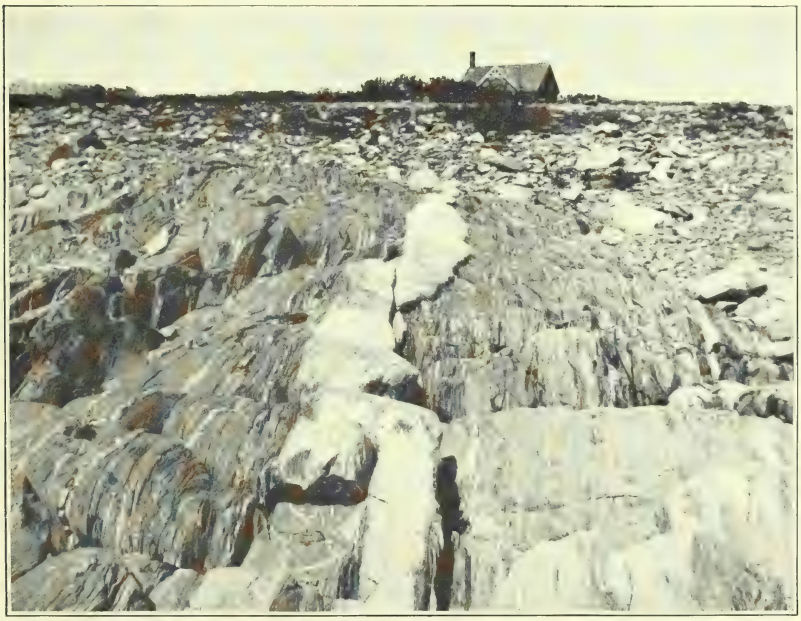
Methods of casing.—Properly constructed drilled wells are so cased that absolutely no surface water can enter the well. It is rarely necessary or desirable to case rock wells far into the rock, but the casing should always be driven through the surface deposits and several feet into the bed rock. If a tight joint is not made with the bed rock an opportunity is furnished for polluted surface water to enter between the casing and the rock. In Government wells the casing is generally driven 12 feet into the ledge. If the bed rock is within a few feet of the surface, it is well to dig around the outside of the casing and cement it firmly to the rock.

Pl. IX, *B*, shows a type of well which is seen far too often. The top of the casing is not even attached firmly to the pump or covered over, but is open in such a way that surface drainage or small animals might easily enter it. The owners of such unprotected wells are advised to close the pipes at the surface. Pls. V, *B*, and IX, *A*, show the proper method of protecting the well by a coating of cement.

Kind of casing.—Galvanized iron pipe is commonly used for casing wells, and as a rule is serviceable. In some places in Maine, however, the galvanized iron imparts a very disagreeable taste to the water, making it unfit for drinking. The water, through some acid property, attacks the pipe, eating pin holes through it, and the well has to be abandoned or recased. Generally ordinary iron pipe is free from this disadvantage, but in places trouble is experienced with this also. Block-tin pipe, though expensive, is as a rule little acted on by water. A well at New Harbor, in Lincoln County, was first cased with galvanized iron, but the taste of the water was too strong. A change was then made to a block-tin pipe, but the water ate pin holes in it and finally wooden pipe had to be put in. An example of the trouble caused by the use of galvanized iron is furnished by the experience of the Rumford Falls Water and Power Company. (See p. 184.)

A. SLATY ROCK ALONG THE COAST, CHRISTMAS COVE.

Showing nature of rock in which poor water of that vicinity is found.



B. OUTCROP OF ROCK ALONG COAST, FORTUNE ROCK, BIDDEFORD.

Showing alternation of hard and soft layers.

INJURY TO WELLS BY SEA WATER.

At a number of places along the Maine coast, especially on the islands, ocean water has entered through crevices in the rock and mingled with the well water to such an extent that the well has had to be abandoned. As a rule trouble with salt water occurs where the rock is slate. In a few places, however, salt-water wells have been obtained in granite. A well owned by Mrs. Kiesel in the town of Islesboro obtained good water at 181 feet from the surface, but drilling was continued, and at 220 feet salt water was encountered. The well was filled with Portland cement to a depth of about 200 feet from the top, the sea water being thus shut out, and the water was reported of good quality in 1906.

In other wells fresh water is first obtained, but after continued pumping the water becomes salt. Such was the case in the Thorp well on Greenings Island, off Mount Desert, which rises and falls with the tide. The water in the R. A. Foss well in Scarboro, 200 feet deep and situated 200 or 300 feet from salt water, was good for a month, but then became salty.

An interesting well is that of the Consolidated Electric Light Company of Maine, at Portland. In 1887 this well was drilled 136 feet and obtained good water. Like the Kiesel well, it was deepened in the hope of getting a larger supply, and salt water was encountered. The total depth of the well was 204 feet. In 1890 it was plugged. The plugging shut off much of the magnesium carbonate and calcium carbonate content of the water and increased the sodium chloride considerably.

An example of the entrance of sea water occurs in the town of Sorrento, which lies on a small neck jutting out from the mainland opposite Sullivan. The slate on this neck is very hard, dense, and fine grained and breaks up on the weathered outcrop into small angular blocks a few inches square. The strike and dip of the strata are variable. In some places the cleavage agrees with the stratification, but in others it does not. Clay 5 to 10 feet thick overlies the slate along the shore, and it is probable that this would prevent the accumulation of much water on the surface of the peninsula. The outcrops along the coast show that the rock is deeply fissured by wave action, some vertical cracks a foot or more across running in for a distance of several feet. As some of the fissures are inclined toward the south, it is probable that the sea water enters the rock on the north side of the peninsula and makes its way far below the surface into wells. This will explain why the only two wells drilled on the peninsula were failures, so far as finding fresh water was concerned. Pl. X, *A*, gives an idea of the character of rock along the coast in which salt water is sometimes found.

SHOOTING WELLS.

In many parts of the country, and particularly in the oil regions, it has been the custom for many years to explode heavy charges of nitroglycerin in the bottom of deep rock wells. This practice increases the yield of many of the wells enormously, greater amounts either of oil or of water being obtained. The increase in yield is due to the fracturing of the rock by the force of the explosion, cracks being formed in which the liquid can move more freely through the rock toward the well.

In many regions water wells have been "shot" with success, and this leads to the question whether that method might not be used in Maine. A few experiments have been tried by certain drillers, who have exploded charges at the bottom of deep wells. It is found that in a hard rock like granite the explosion will form small cracks, and in a few instances water has entered from a near-by seam and supplied the well. Softer rocks, however, like slate and schist, are little broken up, and definite cracks are not formed; hence it is hardly worth while to shoot wells in these rocks. A crooked well drilled at Bath, 90 feet in depth, was shot with 75 pounds of dynamite, but it did no good. This well is situated in the area of complex.

Dr. Charles G. Weld, of North Haven, has two successful wells 12 feet apart, 114 and 140 feet deep. These wells were connected by exploding torpedoes at a depth of 114 feet in both of them.

A number of crooked holes have been straightened by shooting. A prominent well driller has informed the writer that an explosion of dynamite in a crooked hole is frequently much better than reaming it. Generally 75 to 150 pounds of dynamite are used. The explosion makes very little shock, but sometimes scatters water and pebbles several hundred feet from the well.

DATE OF DRILLING.

Study of the well records given in Professor Bayley's table (pp. 242–259) shows that nearly half the wells in southern Maine have been sunk within the last decade. In the farming regions of the State drilling has been largely a necessity, and for that reason considerable was done as early as the eighties, and the number of wells drilled annually does not seem to have increased materially since then. But in the summer-resort regions, which are mostly situated on or near the coast, the greater part of the drilling has been done since 1899. There was some drilling in these sections as early as 1890, but during the early nineties few wells were put down on account of the general industrial depression of the country. The following table has been compiled from the well records in order to give an idea of the relative number of wells drilled in each decade:

Number of wells drilled in southern Maine, by decades.

Before 1880	2
1880–1889	72
1890–1899	133
1900–1906	183
	390

The total is less than the number of drilled wells reported in the table, for the reason that many owners or drillers have failed to report the year in which their wells were drilled.

PUBLIC SUPPLIES.

GENERAL STATEMENT.

Classification of sources.—Public water supplies in Maine are drawn in part from surface sources, including rivers, streams, and ponds, and in part from springs and wells. Some of the surface sources are so situated that the water is of good quality. Springs are good when they are properly situated, and wells are always desirable if they are deep and properly cased. Several towns use more than one of these sources, and some communities have changed from surface to underground supplies or vice versa.

Ownership of public water systems.—A preliminary list of the cities and villages possessing water-supply systems was given by W. S. Bayley in 1905,[a] the lists being obtained through correspondence. During the summer of 1906 several months of field work was done by the writer, and the lists were enlarged considerably. The following paragraphs in quotation marks are from the notes of Professor Bayley:

"As a result of the investigations, the water systems of the State fall into three groups with reference to ownership. The first and most numerous group is that owned by incorporated stock companies; a second group embraces those owned by private parties; and a third group includes those owned by cities or town corporations or by water districts. The third group embraces the smallest number of systems, but they are the largest, since they include the systems supplying the largest communities. As a rule the service is managed directly by the corporate officers in villages, or by water commissioners in cities.

"In recent years another method of management has come into vogue. When a community has reached the limit of its borrowing capacity, or is too small to warrant the construction of an independent system, a water district is formed, usually embracing two or more distinct municipalities, but perhaps including only a portion of a single

[a] Water-Supply Paper U. S. Geol. Survey No. 114, 1905, pp. 40–47.

one. The affairs of the district are managed by a board of trustees chosen by the officers of the municipalities interested. The water rates are established by these trustees, and the profits arising from the operation of the plant, after paying running expenses and providing a certain sum for the maintenance of a sinking fund, are turned into the treasuries of the municipalities.

History.—"Until recently nearly all the public supplies of Maine were obtained from surface sources, such as lakes and streams. In recent years, however, because of the increasing difficulty of finding uncontaminated surface supplies, there has been a tendency to utilize the underground resources wherever possible. Many villages situated in the rural districts have always used spring water, which is conveyed to them in pipes, and in many places small groups of houses are supplied in the same way, but these systems have usually been owned by private parties and not by public corporations. In late years there has been a rapid increase in the number of public systems furnishing spring water. It is plain, however, that since springs are limited in capacity, the size and number of communities which can depend on them for their public supply must likewise be limited. When this limit is reached recourse must be had to wells, if an underground supply is desired, or to lakes if suitable ones are within reach."

Comparative use of various sources.—With reference to their sources of supply the communities have been grouped under three heads—those obtaining water from springs, those using wells, and those supplied by rivers, streams, and lakes. Nearly all the large cities use lake water, as this is found to be more satisfactory than river water, because the great quantity of waste matter discharged into the streams from factories and the numerous settlements along their banks often renders them unfit for domestic use. Of the larger communities, only Bangor, Biddeford, and Saco continue to draw their supplies from streams. Augusta, Waterville, and Rumford Falls have recently changed from rivers to lakes, and Brunswick from a lake to wells. Several others of the smaller communities are agitating a change from rivers to lakes or wells, and the trend of opinion in Bangor is to the effect that Penobscot River must soon be abandoned.

The accompanying lists contain 151 names of communities that are receiving water distributed through pipes and delivered in houses. Of these, 29 obtain their supply from springs, 13 from wells, and 109 from surface sources. The names of several of these communities are duplicated, as a few receive their water from two sources, and others are at present changing from one source to another. Exclusive of duplicates, the number of communities purchasing water distributed through pipes is 148. The lists give the most important data that have been collected with

respect to the water-supply systems in the southern part of the State. They are believed to contain the names of practically all the communities enjoying water service, but a few communities may have been overlooked.

Relative merits of sources.—The choice between a surface and an underground source of supply for any community must be controlled by several factors. In the first place, not all communities are so situated that the most desirable source of supply is near at hand. In certain districts it is almost impossible to obtain a good water supply. In others it is necessary to use streams which are contaminated by sewage and manufacturing wastes from towns situated farther upstream. Many of these communities may be situated in places where no adequate underground supply can be obtained, and such is especially the case with large cities for the reason that the yield of wells always has a maximum limit. Where the quantity of water from wells is not sufficient it is generally necessary to resort to surface sources, even though the water may not be as pure as desired. In all cases the quality of the water should be considered first, as on this depends the health of the people who drink it. Another feature which must be considered in certain districts is the amount of mineral matter contained in the water. Where the supply is desired largely for boilers or manufacturing purposes the amount of contained lime and other dissolved matter should be small, but in Maine this factor is generally not high enough to render the water detrimental.

COMMUNITIES USING WELL SUPPLIES.

There are 13 communities in southern Maine which obtain their public water supplies from driven or drilled wells. All these supplies are believed to be of excellent quality. The communities are enumerated in the following table, and the owners, sources, and methods of distribution are given for convenience of reference. A full description of these water supplies is given under the county headings.

Water systems in southern Maine using wells as sources of public supply.

No.	Community.	County.	Population.	Owner.
1	Brunswick	Cumberland	5,210	Brunswick and Topsham water district.
2	Castine	Hancock	936	Castine Water Co.
3	Cushing Island	Cumberland		Francis Cushing.
4	Great Diamond Island	do	450	Diamond Island Association.
5	East Northport	Waldo	150	Mountain Spring Water Co.
6	Hancock Point	Hancock	100	Village corporation.
7	Peaks Island	Cumberland	500	C. E. Rounds Water Co.
8	Rumford Falls	Oxford	2,595	Rumford Falls Light & Water Co.
9	Sanford	York	2,000	Sanford Light and Water Co.
10	Southwest Harbor	Hancock	720	Southwest Harbor Water Co.
11	Topsham	Sagadahoc		Brunswick and Topsham water district.
12	Warren	Knox	2,069	Warren Water Co.
13	Winthrop	Kennebec		Winthrop Cold Spring Water Co.

Water systems in southern Maine using wells as sources of public supply—Continued.

No.	Source.	Quality.	Method of distribution.
1	50 driven wells	Soft	Pumped into reservoir.
2	Drilled wells	do	Reservoir.
3	do	do	Tank on hill.
4	do	Hard	Pumped into reservoir.
5	Drilled well and springs	Soft	Do.
6	Old mine shaft	do	
7	Drilled wells		Do.
8	75 driven wells	Soft	Pumped to standpipe.
9	Dug and driven well		Reservoir.
10	2 drilled wells	Soft	Pumped to standpipe.
11	50 driven wells	do	Pumped to reservoir.
12	Drilled well	do	Pumped by windmill and gasoline engine to reservoir.
13	Drilled wells	Hard	Pumped to reservoir by windmills.

COMMUNITIES USING SPRING SUPPLIES.

More than twice as many villages draw their water supply from springs as from wells. These, 29 in number, are enumerated in the following table, and the owners, sources, and methods of distribution of water are given for convenience of reference. A full description of these supplies will be found under the appropriate county descriptions.

Water systems in southern Maine obtaining public supplies from springs.

No.	Community	County.	Population.	Owner.
1	Addison Point	Washington	150	Addison Point Aqueduct Co.
2	Bingham	Somerset	800	J. J. Lander et al.
3	Bolsters Mills	Cumberland		Alfred R. Clark.
4	Brooks	Waldo	300	Consolidated Water Co., of New Hampshire.
5	Casco	Cumberland	100	S. O. Hancock.
6	Cherryfield	Washington		Several small systems.
7	East Northport	Waldo	3,000	Norten Spring Water Co.
8	Farmington Falls	Franklin	200	Stock company.
9	Friendship	Knox	300	Friendship Water Co.
10	Hallowell	Kennebec	2,714	City of Hallowell.
11	Harrington	Washington	1,200	Two aqueduct companies.
12	Lamoine	Hancock		Cold Spring Water Co.
13	Lisbon Center	Androscoggin	100	
14	Lisbon Falls	do	1,585	Sylvester Aqueduct Co.
15	Lubec	Washington		Town of Lubec.
16	Milbridge	do		Milbridge Water Co.
17	North New Portland	Somerset	360	
18	North Waterboro	York	230	Chase & Johnson.
19	Orrington	Penobscot		
20	Paris Hill	Oxford	251	Paris Hill Water Co.
21	Ridlonville	do	143	Shaw-Ridlon Land Co.
22	Searsmont	Waldo		L. B. Cobb & Son.
23	Skowhegan	Somerset	6,000	Several aqueduct companies.
24	Stratton	Franklin		
25	Union	Knox	1,000	Union Water Co.
26	Vienna	Kennebec		
27	Winthrop	do		Several well systems.
28	Yarmouth	Cumberland		Town of Yarmouth.
29	Yarmouthville	do	1,000	Do.

Water systems in southern Maine obtaining public supplies from springs—Continued.

No.	Source.	Quality.	Method of distribution.
1	Spring 1 mile distant	Soft	Direct pressure.
2	Several springs	do	Do.
3	2 springs near by		Do.
4	Spring 2 miles distant	"Hard"	Do.
5		Soft	
6	Springs near by	do	Do.
7	Well and springs	do	Reservoir.
8	Springs near by	do	Direct pressure.
9	Springs	do	From tank pumped by windmill.
10	Springs on Winthrop Hill	do	Direct pressure.
11	Springs not far from town	do	Do.
12	Springs	do	Pumped to reservoir by windmill.
13	do		
14	2 springs	Soft	Direct pressure.
15	Marston's spring	do	Direct to standpipe.
16	2 springs	do	Direct pressure.
17	Springs		
18		Soft	Do.
19	Whidden Jpring		
20	Crocker Hill Springs	Soft	Do.
21	Springs		
22	Dyer's spring		Do.
23	Springs	Soft	Do.
24	do		
25	2 springs 1½ miles distant	Soft	Do.
26	Springs		
27	Springs and wells	Soft	Do.
28	Forest Paper Co.'s spring	do	Standpipe.
29	do	do	Do.

COMMUNITIES USING SURFACE SUPPLIES.

Of the 148 communities having public water supplies in the southern part of the State, 109 use water from lakes, ponds, rivers, or brooks. In a description of underground-water supplies it is important for purposes of comparison to record what communities are using surface sources. Moreover, towns sometimes change from surface to underground sources or vice versa. For these reasons a table of the communities using surface sources is appended.

Water systems in southern Maine obtaining public supplies from surface sources.

No.	Community.	County.	Population.	Owner.	Source.
1	Asticon	Hancock	50		Jordans Pond.
2	Auburn	Androscoggin	12,951	Auburn Aqueduct Co	Lake Auburn.
3	Augusta	Kennebec	11,683		Lake Cobbosseecontee.
4	Bangor	Penobscot	21,850	Public Works Co	Penobscot River.
5	Bar Harbor	Hancock	2,500	Bar Harbor Water Co	Eagle Lake.
6	Bath	Sagadahoc	10,477	Maine Water Co	Lake Nequasset.
7	Bayville	Lincoln	57		Adams Pond.
8	Belfast	Waldo	4,615	Belfast Water Co	Little River.
9	Belgrade	Kennebec		Belgrade Water Co	Belgrade Lake.
10	Benton	do		Kennebec water district	China Lake.
11	Bethel	Oxford	722	Bethel Water Co	Chapman Brook.
12	Biddeford	York	16,145	Biddeford and Saco Water Co.	Saco River.
13	Boothbay Harbor	Lincoln	2,000		Adams Pond.
14	Brewer	Penobscot	4,835	Public Works Co., Bangor	Penobscot River.
15	Buckfield	Oxford	379		South Pond.
16	Bucksport	Hancock		Bucksport Water Co	Silver Lake.
17	Camden	Knox		Camden and Rockland Water Co.	Mirror Lake.
18	Cape Elizabeth	Cumberland		Portland water commissioners.	Sebago Lake.

Water systems in southern Maine obtaining public supplies from surface sources—Cont'd.

No.	Community.	County.	Population.	Owner.	Source.
19	Cape Neddick	York	164	York Shore Water Co.	Chase Pond.
20	Cape Porpoise	do	420	Mousam Water Co.	Morson River.
21	Chisholm Mill	Franklin	800	Livermore Falls Water Co.	Moose Hill Lake.
22	Damariscotta	Lincoln		Twin Village Water Co.	Little Pond.
23	Dexter	Penobscot			Dexter Pond.
24	East Lamoine	Hancock	170		Blunts Pond.
25	Eastport	Washington	5,311	Eastport Water Co.	Boydens Pond.
26	Ellsworth	Hancock	4,297	Ellsworth Water Co.	Branch Pond Stream.
27	Ellsworth Falls	do	400	do	Do.
28	Fairfield	Somerset	3,800	Kennebec water district	China Lake.
29	Falmouth Foreside	Cumberland	175		Sebago Lake.
30	Farmingdale	Kennebec		Gardiner water district	Cobbosseecontee Stream.
31	Farmington	Franklin	1,200		Varnum Pond.
32	Freeport	Cumberland	759	Freeport waterworks	Frost Galley Brook.
33	Fryeburg	Oxford	550	Fryeburg Water Co.	Two brooks in Conway, N. H.
34	Gardiner	Kennebec	5,501	Gardiner water district	Cobbosseecontee Stream.
35	Glencove	Knox	117		Mirror Lake.
36	Gorham	Cumberland		Gorham Water Co.	Sebago Lake.
37	Great Works	Penobscot			Penobscot River.
38	Hallowell	Kennebec	2,714		Cobbosseecontee Stream.
39	Hartland	Somerset		Linn Woolen Co.	Sebasticook River.
40	Hastings	Oxford	200		Brook.
41	Hebron	do	500	Hebron Water Co.	Halls Pond.
42	Hulls Cove	Hancock	177	Bar Harbor Water Co.	Eagle Lake.
43	Kennebunkport	York	2,100	Mousam Water Co.	Branch Brook.
44	Kennebunk	do		do	Do.
45	Kennebunk Beach	do	170	do	Do.
46	Kennebunk Landing.	do		do	Do.
47	Kittery	do	1,500	Agamenticus Water Co.	Folly Pond.
48	Kittery Point	do	400		Do.
49	Kingfield	Franklin	700	Kingfield Water Co.	Outlet Tuffs Pond.
50	Lamoine Beach		100		Blunts Pond.
51	Lewiston	Androscoggin	23,760	Lewiston water commissioners.	Lake Auburn.
52	Livermore Falls	do	1,250	Livermore Falls Water Co.	Moose Hill Lake.
53	Machias	Washington		Machias Water Co.	Machias River.
54	Madison	Somerset	1,850	Madison Water Co.	Kennebec River.
55	Mechanic Falls	Androscoggin	1,500	Mechanic Falls Water Co.	Waterhouse Brook.
56	Milford	Penobscot		Public Works Co., Bangor.	Penobscot River.
57	New Castle	Lincoln		Twin Village Water Co.	Little Pond.
58	North Berwick	York			Stream supplied by springs.
59	Newport	Penobscot		Newport Water Co.	Pillsbury Pond.
60	North Vassalboro	Kennebec	850		China Lake.
61	Northeast Harbor	Hancock	350		Hodlock's Lower Pond.
62	Norway	Oxford	2,034	Norway Water Co.	Norway Lake.
63	Oakland	Kennebec	2,500	Oakland Water Co.	Messalonskee Lake.
64	Ocean Bluff	York	375	Mousam Water Co.	Branch Brook.
65	Ogunquit	do		do	Do.
66	Old Orchard	do	1,000	Biddeford and Saco Water Co.	Saco River.
67	Oldtown	Penobscot	5,763	Public Works Co., Bangor.	Penobscot River.
68	Orono	do	3,257	do	Do.
69	Perry	Washington		Eastport Water Co.	Boydens Lake.
70	Phillips	Franklin	674	Moore & Gaming	Mount Blue Pond.
71	Pittsfield	Somerset	2,208	Pittsfield waterworks	Sebasticook River.
72	Portland	Cumberland	50,145	Portland water commissioners.	Sebago Lake.
73	Rangeley	Franklin	563		Cascade Brook.
74	Randolph	Kennebec		Gardiner water district	Cobbosseecontee Stream.
75	Richmond	Sagadahoc		Richmond waterworks	Kennebec River.
76	Rockland	Knox	8,150	Camden and Rockland Water Co.	Mirror Lake.
77	Do.	do	8,150	Rockland Water Co.	Lake Chickawaukee.
78	Rockport	do	2,314	Camden and Rockland Water Co.	Mirror Lake.
79	Rockville	do	150		Do.
80	Saco	York	6,122	Biddeford and Saco Water Co.	Saco River.
81	Seal Harbor	Hancock	250	Seal Harbor Water Supply Co.	Jordans Pond.

Water systems in southern Maine obtaining public supplies from surface sources—Cont'd.

No.	Community.	County.	Population.	Owner.	Source.
82	Searsport	Waldo			Half Moon Pond.
83	Sorrento	Hancock	100	Estate of Frank Jones	Long Pond.
84	South Paris	Oxford	1,457	Norway Water Co.	Norway Lake.
85	South Portland	Cumberland	6,287	Portland water commissioners.	Sebago Lake.
86	South West Harbor	Hancock	720	South West Harbor Water Co.	Long Pond.
87	South Berwick	York	1,000	South Berwick Water Co.	Two Brooks.
88	Skowhegan	Somerset	4,266	Skowhegan waterworks	Brook 1 mile from village (in part).
89	Southport	Lincoln			Adams Pond.
90	Springvale	York	2,000	Springvale Aqueduct Co.	Littlefields Pond.
91	Squirrel Island	Lincoln	50		Adams Pond.
92	Stockton Springs	Waldo			Half Moon Pond.
93	Strong	Franklin	600	Strong Water Co.	Outlet of Day Mountain Pond.
94	Sullivan	Hancock			Long Pond.
95	Thomaston	Knox	2,600	Camden and Rockland Water Co.	Mirror Lake.
96	Veazie	Penobscot		Public Works Co., Bangor	Penobscot River.
97	Waterville	Kennebec	10,000	Kennebec water district	China Lake.
98	Westbrook	Cumberland	7,283	Portland water commissioners.	Sebago Lake.
99	Wells Beach	York		Mousam Water Co.	Branch Brook.
100	West Kennebunk	do	350	do	Do.
101	Wilton	Franklin	2,000		Varnums Pond.
102	Winnegance	Sagadahoc	156		Lake Nequasset.
103	Winslow	Kennebec		Kennebec water district	China Lake.
104	Winter Harbor	Hancock	600	Grindstone Neck Water Co.	Birch Harbor Pond.
105	Winterport	Waldo			West Branch Lowes Brook.
106	Woolwich	Sagadahoc		Maine Water Co.	Lake Nequasset.
107	York	York		York Shore Water Co.	Chase Lake.
108	York Corner	do	250		Do.
109	York Beach	do	500	York Shore Water Co.	Do.

COMPOSITION OF THE UNDERGROUND WATERS.

GENERAL EXPLANATIONS.

Classes of analyses.—The analyses reported in the table on pages 77–87 include all chemical analyses (mineral analyses) of Maine well and spring waters that could be obtained. They may be grouped in four classes:

(1) "Field assays," or approximate analyses of half-pint samples made in the field by F. G. Clapp, G. C. Matson, and B. L. Johnson, of the United States Geological Survey.

(2) Analyses of 1-gallon samples shipped to Prof. F. C. Robinson, at Bowdoin College, Brunswick, Me., and analyzed by him.

(3) Analyses made by W. W. Skinner, of the United States Department of Agriculture, in connection with cooperative work between the Geological Survey and the Bureau of Chemistry.

(4) Analyses made by other persons.

The first group of analyses are designated "assays" for the reason that they were made with a field outfit to obtain a general idea of the character of the water.[a] They do not pretend to be refined analyses, and are published only because it was impracticable, on account of

[a] Leighton, M. O., Field assay of water: Water-Supply Paper U. S. Geol. Survey No. 151, 1905.

expense, to make more than 70 analyses of the second group, and only 10 of the third group had been made.

In order that the reader may form a graphic idea of the proportions of the different ions in various rocks and localities, the analyses of the second group have been plotted on Pls. IV, VI, and VIII.

Recomputation of analyses.—The analyses made by the United States Geological Survey are uniformly reported in ionic form and parts per million. Analyses obtained from miscellaneous sources, however, were originally given as parts per million, parts per 100,000, or grains per gallon, and were mostly reported in the form of the chemical compounds in which the minerals are supposed to exist. Chemical research shows that there is no certainty that the elements are combined in this form, the compounds given in most analyses being mainly theoretical. For this reason all analyses which were not expressed according to the standard method when received by the writer were recomputed into ions and parts per million, and they are expressed in this form in the table.

Omission of sanitary analyses.—Few sanitary analyses are included in this report, although hundreds of them have been made by the state board of health and other analysts. The reason for this omission is that sanitary analyses record only those constituents of a water which may be present by reason of its pollution or the entrance of organic matter in other ways. The substances reported in a mineral analysis of water, however, are with few exceptions, derived from materials dissolved from rocks or surface deposits, and are at all times nearly the same for a given well or spring, varying only with the amount of rainfall, the height of the water level, or, in the case of a well, with the age of the well. The substances reported in a sanitary analysis are chlorine, ammonia, nitrites, and nitrates—substances that are formed during the decay of organic matter, and consequently are present in soils, sewage, and other wastes. The amount of these impurities varies from time to time according to local conditions.

Much has been written in scientific journals regarding the value or worthlessness of a sanitary analysis. The best chemists of the world now agree that it is of value only when considered in connection with other matters, such as the location of the well or spring with reference to sources of pollution. As the present paper is designed for permanent reference, and as sanitary analyses of any water vary from time to time, only a few such analyses are given here. Others may be found in the annual reports of the state board of health, to which interested persons are referred.

DETAILS.

Tables.—The following tables contain nearly 300 analyses of well and spring waters. The well table is subdivided according to the kind of rock penetrated.

Analyses of well waters in southern Maine.

[Parts per million.]

WELLS IN GRANITE.

No.	Locality.	Owner.	Type.	Depth (feet).	Color.	Total solids.	Organic and volatile matter.	Silica (SiO_2).	Iron and aluminum oxides ($Fe_2O_3+Al_2O_3$).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl.)	Total hardness as $CaCO_3$.	Analyst.[a]
	Androscoggin County:																		
1	Lisbon	R. A. Small	Drilled	(?)	4					0					107	tr.	14		F
2	South Poland	Chas. Gould and W. F. Trask	do			[b]98		18.17		0.51	19	2.2	7.9	0.5		13			H
	Cumberland County:																		
3	Bridgton	F. H. Abbott	(?)	(?)	2					0					73	0	9.6		F
4	Do	F. P. Bennett	Drilled	(?)	0					0					21	0	36		F
5	Do	J. K. Martin	do	125		206	74	31.1	2.8		29	7.6	9.6	6.9		9.6	24		R
6	Do	Granville Morrison	do	72	11					0					44	tr.	4.7		F
7	Do	Unknown	do	125	45					0					45	tr.	9.6		F
8	South Freeport	J. H. Lea	do	108	39					tr.					118	([c])	9		F
	Hancock County:																		
9	Eden	Edw. Morrell	do	87	6					0					99	tr.	14		F
10	Greening's Island, Northeast Harbor.	J. G. Thorp	do	88		81	5.2	8.5	1.1		1.1	1.8	11	1.7		15	23		R
11	North Sullivan	C. H. Abbot	do	37	0					0					9	tr.	24		F
12	Do	John M. Blaisdell	do	25	0	196	27	8.3	4.7		37	4.3	26	5.6		15	41		R
13	Do	Crabtree & Haney	do	51	23					0.5					50	tr.	102		F
14	Do	do	do	51		364	67	12.5	2.1		62	3.4	62	3.7		16	140		R
15	Stonington	Samuel W. Goss	do	67	26					1					98	tr	58		F
16	Do	R. B. Judkins	do	67		156	48										32	53	H
17	Crotch Island, Stonington.	Ryan-Parker Construction Co.	do	300	4					1					15	125	70		F
18	The Settlement, Stonington	J. C. Rogers	do	93⅔	0					0					27	([c])	14		F
19	Do	do	do	279		136	19	11.2	2.0		29	3.4	13	1.9		26	17		R
20	Kennebec County: Augusta.	Chas. F. Tittetts	Blasted	30		42	18										4	30	H
21	Knox County: Vinalhaven	Glue factory	Drilled	230		4,056	1,046	194.7	1.4		404	131	465	140		122	1,790		R
	Lincoln County:																		
22	Bristol	J. W. P. Gowdy	do	52	0					0					33	tr.	22		F
23	Damariscotta	Mrs. G. C. Chapman	do	87	0					0					123	([c])	58		F
24	Damariscotta Mills	G. W. Waltz	do	64		129	29	23.8	2.5		18	2.9	13	5.8		14	15		R
25	Pemaquid Beach	C. A. Sproul	do	45		919	272	13.7	7.1		45	14	134	49		46	334		R
26	Pemaquid Harbor	C. A. Farrin	Blasted	25	22					5					6	([c])	32		F
27	Waldoboro	R. L. Benner	Drilled							0					143	([c])	4.3		F
28	Do	Miss E. F. Genthner	do	56		419	100	10.9	3.5		57	9.0	30	13		36	57		R

[a] F, Field assay by F. G. Clapp, G. C. Matson, or B. L. Johnson; R, F. C. Robinson, analyst; H, Sanitary analysis by state board of health.

[b] Includes lithium (Li), trace; carbonate radicle (CO_3), 36. ("Apollo water.")

[c] SO_4 less than 35 parts per million.

Analyses of well waters in southern Maine—Continued.

WELLS IN SLATE.

No.	Locality.	Owner.	Type.	Depth (feet).	Color.	Total solids.	Organic and volatile matter.	Silica (SiO_2).	Iron and aluminum oxides ($Fe_2O_3 + Al_2O_3$).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total hardness ($CaCO_3$).	Analyst.
	Cumberland County:																		
29	Cape Cottage	Amos Miller	Drilled	115		140	22	9.0	0.9		43	2.4	11	3.8		15	18		R
30	Gorham	Dan Cressey	do	66	20					0					76	(a)	20		F
31	Great Diamond Island	Diamond Island Ass'n	do	120		120	14	16	.8		15	6.4	10	3.0		9	11		R
32	Portland	do	do	96	0					0						46	40		F
33	Mere Point	W. D. Pennell	do	67		88	30	8.8	2.0		7.0	4.5	7.3	1.5		22	30		R
34	Portland	Beacon Hill Water Co.	do	70	0					0					61	49	18		F
35	Peaks Island	C. W. T. Goding	do	135		183	40	4.7			27	0.4	18			25	27	(b)	
36	Do	Mrs. E. Lefavor	do	40		52	22										1	17	H
37	Portland	Jas. P. Baxter	do	164	8					0					170	64	185	103	F
38	Do	Chas. A. Brown	do	60		160	48										38	67	
39	Do	E. T. Burrows	do	106	9					0					102	83	100	176	F
40	Do	Consolidated Electric Light Co.	do	[b]204		2,008													
41	Do	James Cunningham	do	35		142	26										24	81	
44	Do	M. R. Griffith	do	178		644	192										212	172	
45	Do	Maine General Hospital	do	505		177	0.5	11		2.5	13	4.3	38	11		6.8	4.5	1[illegible]	1[illegible]
46	Do	John T. Palmer	do	161		610	54										102	81	
47	Do	G. F. Thurston	do	40		140	90										14	46	
48	Scarboro	H. J. Libby estate	do	200	7					0					79	38	12		F
49	Do	do	do	200		145	13	12.1	2.6		12	4.7	12	17		24	14		R
50	Standish	R. W. E. Shaw	do	86	0					tr.					101	41	7.1		F
51	Westbrook	Haskell Silk Co.	do			344	60	1.35	tr.		24	7.8				32		60	
52	Do	Rufus Jordan	do	216	6					0					78	(c)	8		F
53	Do	do	do	216		129	18	19	2.6		24	3.0	10	3.7		46	7.5		R
54	Do	J. H. Rines	do	307	5					0					98	46	13		F
	Hancock County:																		
55	Bucksport	Eastern Maine Conference Seminary.	do	308		116	9.6	15	1.8		26	3.6	18	2.2		22	6.5		R
56	Do	do	Open	Few		53	5.6	8.9	1.1		9	1.4	7.6	1.4		9	9.2		R
57	Hancock	Jeremiah Stratton	Drilled	65		109	16	15	1.0		15	2.9	6.7	2.3		11	12		R
58	Orland	Mrs. A. W. Emerson	do	42	9					0.1					28	19	4		F
59	Do	Mrs. A. W. Hutchins	do	77	12					high					32	16	5.4		F
	Kennebec County:																		
60	Farmingdale	H. M. Hodgdon	do	107		170	66										32	103	
61	Do	Tibbetts & Sawyer	do	80	33					1.7					37	29	46		F
62	Gardiner	Chas. Hopkins	do	34		258	40	20	1.4		39	6.9	36	11		21	64		R

63	Sidney	G. F. Bowman	do	96	6					0					37	tr.	121		F
64	Winslow	J. L. Dean	do	65	4					0					153	tr.	7.5		F
65	Do	Will Glidden		30	11					0					49		1.9		F
66	Do	J. F. Howard	Open	(?)	60										135	(m)	10		F
67	Winthrop	C. M. Bailey Sons & Co	Drilled	307½		227	20	16	2.0		57	6.3	27	5		63	7.5		R
68	Do	do	do	307½	0					0					95		13		F
69	Do	Frank S. Wood	do	175		217				0.35							4.7	67	(e)
70	Winthrop Center	Mrs. H. J. Bailey	do	200	0					0					99	tr.	11		F
	Knox County:																		
71	Rockport	The Roxmont	Open	16											35	tr.	14		F
	Penobscot County:																		
72	Bangor	Bangor House	Drilled	290	4					0					519	52	55		F
73	Do	do	do	290		834	150	17	1.0		214	32	46		(f)	63	58		
74	Do	Jos. E. Buckley	do	30	0	150											12	60	(g)
75	Do	Eastern Maine Insane Hospital.	do	425	0					0					146	tr.	15		F
76	Do	High School	do	217		491	124			0.02							46	260	(h)
77	Do	do	do	217	0					0					224	42	46		F
78	Do	do	do	217		180	37	10	1.1		46	7.4	12	1.3		18	50		R
79	Do	do	do	217		441	62	i 7	j tr.	10	82	15	33				102	258	(g)
80	Do	H. F. Hanson	do	35		436	190										76	229	
81	Do	F. L. Jones	do	247½	0					0						20	72		F
82	Do	Maine Creamery Co	do	120	0					0					121	145	22		F
83	Do	do	do	120			11										2.7	(k)	
84	Do	do	do	180		86	21	6.7	0.7		20.1	5.7	4.0	0.8		5.9	21		R
85	Do	Morse & Co	do	255	0					0					160	(m)	16		F
86	Do	Palm Street School	do	72		256	61			0.2							24	185	(h)
87	Do	do	do	72		233	58	l 8.1	j tr.	8.4	44	11	11				38	200	(g)
88	Do	Penobscot County court-house.	do	200½	0	242	40										46		(g)
89	Do	do	do	200½	0					0					221	(m)	76		F
90	Do	Union Square School	do	203		439	103			tr.							54	298	(a)
91	Do	do	do	203	0					0					266	(m)	50		F
92	Charleston	A. A. Dority	do	38	0										157	tr.	5.7		F
93	Do	J. H. Higgins	do	33		93	16	7	1.2		18	6.8	3.1	1.6		6.6	1.4		R
94	Do	C. H. Scribner		16	0										199	tr.	14		F
95	Corinna	Wm. Pitcher			27					tr.					317	tr.	32		F
96	East Newport	L. D. Babb	Drilled	71½	67					0.5					104	tr.	11		F
97	Do	J. P. Chadbourne	do	63		424	92										64	188	
98	Do	J. B. Chadbourne	do	57		474	158										80	320	
99	Do	R. C. Chadbourne	do			74	11	12	1.5		14	4.0	3.5	1.4		4.6	6		R
100	Hampden	Mrs. A. J. Bragg	do	103	69					tr.					35	(m)	10		F
101	Do	Cyrus Moulton	do	75+	20					0					109	(m)	25		F
102	Do	C. L. Philbrick	do	50	15					0					56	0	20		F
103	Hampden Corners	Town well	Blasted	28	2					0					110	(m)	52		F
104	North Dixmont	S. E. Harris	Drilled	55	44					tr.					316	40	112		F
105	Orrington	Archie Harding	do	50	4					0					73	tr.	8.7		F
106	Stetson	F. P. Abbott				165	37	8.3	2.1		4.2	8.2	4.5	3.1		7.1	8		R

a Carbonate radicle (CO_3), 40.
b Well plugged at 145 feet; salt water.
c Carbonate radicle (CO_3), 84.
d E. L. Robinson.
e Chas. Harrington.
f Carbonate radicle (CO_3), 140.
g Ora W. Knight.
h H. D. Evans.
i Includes some suspended clay.
j Al_2O_3.
k When drilled hardness 140.
l With suspended clay.
m SO_4 less than 35 parts per million.

Analyses of well waters in southern Maine—Continued.

WELLS IN SLATE—Continued.

No.	Locality.	Owner.	Type.	Depth (feet).	Color.	Total solids.	Organic and volatile matter.	Silica (SiO_2).	Iron and aluminum oxides ($Fe_2O_3 + Al_2O_3$).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total hardness (as $CaCO_3$).	Analyst.
	Sagadahoc County:																		
107	Bowdoinham	E. C. McFarlane			45					0					134	(a)	35		
	Somerset County:																		
108	Norridgewock	G. C. Haynes	Drilled	26	0					0					35	tr.	3.5		F
109	Pittsfield	W. R. Hinnewell	Dug	47		56	16										5	35	
110	Do	F. J. Taylor	do	26		408	74										48	188	
	Waldo County:																		
111	Belmont	Horace Chenery	Drilled	187		138	9.5	17	2.5		23	6.4	15	6.1		14	5		R
112	Cape Jellison	Northern Maine Seaport R. R. Co.	do			104	25	12	[b] tr.	10	18	6.2				tr.	7	(a)	(d)
113	Islesboro	R. A. Boit	do	398	0					0					149	tr.	33		F
114	Do	Islesboro Land and Improvement Co.	do	149	0					0					155	tr.	22		F
115	Do	M. E. Lewis	do	150		145											11	85	
116	Do	H. T. Sloan	do	198	0					0					104	tr.	7.7		F
117	Jackson	E. E. Morton	do	45	22					tr.					75	0	36		I
118	Kidders Point	Northern Maine Seaport R. R. Co.	do			146	24	16	[c] tr.	10	20	4.2				0	8	(a)	(d)
119	Monroe	Nathan Stearns	do	60		164	50	13	1.2		37	6.3	7	2.7		14	8.5		R
120	Do	do	do	60	22					0.5					95	(a)	8.7		F
121	Searsport	Northern Maine Seaport R. R. Co.	do	329½	102					2					62	(a)	65		F
122	Do	W. E. Grinnell	do	100		162	11	21	3		28.4	5.1	21	6.2		28	22		R
123	Do	Northern Maine Seaport R. R. Co.				101	13	21	[c] tr.	5.2	8.5	2.7				tr.	7	(a)	(d)
124	Troy	Chas. Harmon	Drilled	40	22					0.5					112	(a)	20		F
125	Winterport	S. Chase	do	57	17					tr.					40	0	14		F
126	Do	J. K. Downs	do	40	17					tr.					90	tr.	7.4		F
127	Stockton Springs	Northern Maine Seaport R. R. Co.	do			104	25	9.5	[c] tr.	9.1	10	1.5				tr.	10	(a)	(d)
	York County:																		
128	Cutts Island, Kittery	Roland Thaxter	do	75	80					1.5					39		29		F
129	Do	do	do	75		209	45	11	3.2		46.8	13	27	8.7		14	40		R
130	Kittery Point	Horace Mitchell	do	60	6					0					63	tr.	44		F
131	Ogunquit	Chas. C. Hoyt estate	do	65		169	11	19	3.2		34.1	6.7	13	7.9		18	20		R

WELLS IN AREAS OF COMPLEX.

	Knox County:																			
132	North Haven	Nelson Mullen	Drilled		10					0					217	(a)	20		F
133	Vinalhaven	Rev. G. A. Strong	do		4					0					88	(a)	40		F
134	Warren	Warren Water Co	do	200	14					0					42	tr.	3.3		F
	Lincoln County:																			
135	Christmas Cove	Everett Wescott	do	100		107	13	10	6.6		4.4	12	17	4.0		14	17		R
136	Do	E. F. Wilder	do			189	22	12	1.9		9.1	5.2	41	5.2		33	61		R
137	Coopers Mills	Chas. H. Ashford	do	65		249	48	7.3	2.6		31	4.9	18	24		21	28		R
138	Do	S. E. Hopkins	do	46	13					¼					96	tr.	24		F
139	East Boothbay	Hodgdon Bros	do	120	25					0					102	15	21		F
140	Do	Frank Rice	do	75	13					0					65	tr.	42		F
141	Do	do	do	75		188	26	17	2.7		16	6.7	29	4.0		17	43		R
142	Heron Island	Wm. C. Damon	do	119		225	34	25	8.5		44	7.6	19	6.5		12	33		R
143	Ocean Point	L. J. Crooker	do	360	25					0					48	tr.	12		F
144	Do	do	do	360		96	9.3	8.8	2.1		9.3	2.6	13	2.5		11	14		R
145	Pemaquid Point	W. A. Elliott	do	51	0					1					148	tr.	33		F
145a	Do	M. B. Macdonald	do	23		115				tr.							34	44	
146	Wiscasset	Customs House	do	79	5					0					238	49	77		F
147	Do	W. G. Hubbard	do	70	7					0					329	77	220		F
148	Do	J. P. Tucker	do	68	8					0					138	25	31		F
149	Do	Wiscasset Jail	do	154		301	18	21	1.3		54	4.7	39	12		46	52		R
	Sagadahoc County:																			
150	Bath	H. Langdon	do		26					0					105	tr.	40		F
151	Do	Roller Bushing Works	do	180	69					0					98	286	918		F
152	Woolwich	F. W. Carleton	do	98		123	28	16	1.9		16	8.3	12	4.0		13	17		R
	Waldo County:																			
153	East Northport	Northport Mountain Spring Co.	do	162	0	145	39			tr.							6.4	88	H
154	Do	Mrs. Mark Mandall	do	64		234	82										58	126	H

WELLS IN IGNEOUS ROCKS OTHER THAN GRANITE.[i]

	Knox County:																			
155	North Haven	F. S. Mead	Drilled	126		2,057	355	22	2.2		515	52	209	7.2		125	956		R
156	Do	G. W. Wheelwright	do	180		90	6.8	10	0		30	1.2	8.9	0.7		4.9	13		R
	Washington County:																			
157	Eastport	Seacoast Canning Co	do	408	25					0					214	70	30		F
158	Do	do	do	408		414	42	48	1.9		108	11	30	3.9		71	36		R
159	Jonesport	do	do	384	22					0.5					28	47	47		F
160	York County: Cutts Island, Kittery.	John Thaxter	Open	6	22					0					70	tr.	19		F

[a] SO_4 less than 35 parts per million.
[b] Al_2O_3.
[c] Temporary, 34; total, 89.
[d] Ora W. Knight.
[e] Al.
[f] Temporary, 35.
[g] Temporary, 25; total, 59.
[h] Temporary 25; total, 55.
[i] Wells 155, 156, 160 are in trap; 157, 158 in greenstone; 159 in diorite.

Analyses of well waters in southern Maine—Continued.

No.	Locality.	Owner.	Type.	Depth (feet).	Color.	Total solids.	Organic and volatile matter.	Silica (SiO_2).	Iron and aluminum oxides ($Fe_2O_3 + Al_2O_3$).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total hardness as $CaCO_3$.	Analyst.
	WELLS IN CLAY.																		
161	Cumberland County: Scarboro.	Jno. H. Leavitt	Dug	19½	0					0					58	(?)	25		F
162	Franklin County: Farmington.	Warren Ladd	do	58	30					0					27	tr	46		F
	Hancock County:																		
163	Brooksville		do	16	109					0					43	0	5.2		F
164	Do		do	14±	7					0					116	33	25		F
165	Kennebec County: Vassalboro.	Geo. C. Gardner	do	16	2					0					79	(?)	12		F
166	Washington County: Lubec		do	30±	148					0					157	47	14		F
167	York County: North Kennebunkport.	Edwin Dennett	do		5					0						tr	40		F
	WELLS IN TILL (BOWLDER CLAY).																		
168	Cumberland County: Portland.	Unknown	Dug	12	33					tr.					40	0	8.6		F
	Hancock County:																		
169	Eden	do	do	16	0					0					16	tr	30		F
170	Orland	do	do	22	0					0					23	(o)	19		F
171	Sorrento	T. N. Nickerson	do	8	38					0					29		41		F
173	Penobscot County: Orono	N. W. Page	do	54	0					0					77	tr	34		F
174	Washington County: Jonesboro.		do	7						0					34	tr	16		F
	WELLS IN SAND AND GRAVEL.																		
	Androscoggin County:																		
175	Auburn	E. H. Libby	Open	27	0					0					31	tr	4.2		F
176	Mechanic Falls		Driven	35	0					0					10	tr	3.2		F
	Cumberland County:																		
177	Brunswick	Brunswick and Topsham Water District.	do	25		55		12	0.2		4.2	1.8	8.9			6.5	4.0	26	

178	Do	do	do			55		11	0.2		3.9	2.3	7.3			11	4.0	26	
179	Do	do	do			42											16	22	
180	Do	Public supply	do		5					0						23	tr.	5.3		F
181	Scarboro	West Boothbay	Open	5	0					0						36	(a)	14		F
182	Do		do	20	0					0						29	tr.	18		F
183	Windham	Geo. E. Dow	do	10	0					tr.						29	tr.	3.3		F
	Hancock County:																			
184	East Orland	Tom Mason	Driven	87½		66	13	16	1.0		6.5	4.1	6.2	1.6		3.7	3.7		F
185	Hancock	Public well	Bored	30½	0					0						32	tr.	11		F
186	Kennebec County: Gardiner.	Mrs. S. R. Hayes	Open	22	20					0.5						33	20	17		F
	Oxford County:																			
187	Rumford Falls	Rumford Falls Light and Water Co.	Driven			36	6	14		0.7	3.3		0.9		(b)	1.8	3.0		R
188	Do	do	do			58	6.6	14		2.2	3.3		0.9		(c)	1.8	3.0		R
189	Do	do	do			37	6.2	14		1.5	3.3		0.9		(d)	1.8	3.0		R
	Washington County:																			
190	Calais	W. A. Rideout	Bored	44	30					0						90	tr.	9.2		F
191	Do	do	do	44		138	16	13	1.7		4.1	5.4	18	3.0		11	12		R
192	Machias	Joseph Smith	Open	21	97					0						128	10	16		
193	Millbridge	Millbridge Water Co	Bored	17	0					0						34	0	8.4		
	York County:																			
194	Berwick	Berwick Water Co			30					1						21	74	8.8		F
195	York	York Harbor Brick Co	Open	10	30					0						190	tr.	9.2		F

MISCELLANEOUS WELLS.[e]

196	Androscoggin County: Auburn.	C. M. Goff				112	5.1	14		0.2	14	1.6	0.1	0.8	(f)	5.3	9.7		
	Hancock County:																			
197	Bluehill	Mrs. Ethelbert Nevin	Drilled		16					0						134	tr.	21		F
198	Do	Dr. A. M. Thomas	do		352					0						112	tr.	15		F
199	Sagadahoc County: Bowdoinham.			140	30					0						93	tr.	31		F
200	Cumberland County: Cushing Island, Portland.	S. W. Thaxter	Dug	72	68	30												8.0	32	H
201	Waldo County: Searsmont	D. B. Cobb	Open	33	0					0						76	0	5.0		F
202	Washington County: Perry	R. R. Newcomb	Dug	22	22					0						81	tr.	20		

[a] SO_4 less than 35 parts per million.
[b] Sample from pumping station; carbonate radicle (CO_3), 5.7.
[c] Sample from end of long galvanized-iron main; carbonate radicle (CO_3), 16.
[d] Sample from Hotel Rumford; carbonate radicle (CO_3), 6.8.
[e] Wells 197, 198, 200 are in gneiss; 201 in till and slate; 202 in sandstone.
[f] Carbonate radicle (CO_3), 41.

Analyses of spring waters in southern Maine.

[Parts per million.]

No.	Locality.	Owner.	Name of spring.	Total solids.	Organic and volatile matter.	Silica (SiO_2).	Iron and aluminum oxides ($Fe_2O_3 + Al_2O_3$).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Carbonate radicle (CO_3).	Total hardness as $CaCO_3$.	Analyst.
	Androscoggin County:																	
203	Auburn		Auburn Diamond.	79			3.4		6.6	14			2.7					R. C. Stanley.
203a	Do.	Samoar Carbonating Co.	Crystal Mineral	74		12	3.1		7.7	3.6				8.3	5.3	23		L. G. Jordan.
204	Do.	Pejepscot Spring Water Co.	Pejepscot	[b] 86	3.1	19	1.1		14	2.6	3.8	1.6		11	2.2	27		Stillwell and Gladding.
205	Durham		Sylvan	29		5.1	2.2		1.5	1.4	3.8	1.1		4.1	8.0	4.0		E. G. Jordan.
206	East Poland	S. M. Pratt	Keystone Mineral.	51	tr.	(c)		6.7		3.2	5.3			2.9	2.6	15		R. C. Stanley.[d]
206a	Do.	do	do	104		12			15	3.1	4.2	0.8	60	3.4	5.2			W. W. Skinner.[e]
206b	Greene	A. B. Parker & Sons	Glenrock Mineral.	67		5.6	(f)	2.2	12	1.8	5.1	3.2		4.0	5.0	26		L. G. Jordan.
207	East Turner		Cliff	30		5.6	1.9		2.6	1.3	2.4			5.2	3.9	7.6		Do.
208	Lewiston	Windsor Mineral Spring Co.	Windsor Mineral.	154		18		0.7	42	1.9	5.8			29	5.1			S. P. Sharples.
208a	South Auburn		American Chalybeate.	174	38	11		8.3	27	5.5	2.2	6.3		11	3.5	61		F. L. Bartlett.
209	Lewiston	Highland Mineral Spring Water Co.	Highland Mineral.	84		11			15	2.6	3.1	8.0		10	5	29		C. F. Chandler.
210	Do.	do	do	82		13				6.0	15			3.6	10	33		R. C. Stanley.
210a	Do.	do	do	52		11			5.9	0.9	2.8	1.2	23	4.6	2.2			W. W. Skinner.[g]
211	North Auburn		Auburn.	65		0.2	tr.	tr.	1.8	0.8	16	1.3	2.1	1.8	2.7			S. D. Hayes.
211a	South Poland		Fountain Head	68		16			5.9	tr.	10	0.8	18	1.1	16			F. L. Bartlett.
212	Do.	Hiram Ricker & Sons.	Poland	63	4.0	19	tr.		8.3	2.7	2.7	1.2		1.4	2.7	21		C. F. Chandler.
213	Do.	do	do			19			8.4	2.7	2.9	1.2		1.5	2.7	21		
214	Do.	do	do			24	0.4		14	2.1	6.9	2.4	48.4	3.0	5.0			U. S. Dept. Agriculture.[h]
214a	Do.	do	do	109		15			14	2.4	6.3	0.9	56	3.3	5.9			W. W. Skinner.[i]
214b	Do.		Star	242	38	9.9	(j)		16	4.0	33	6.7		8.3	50	54		F. L. Bartlett.
	Cumberland County:																	
215	Bolsters Mills	Alfred C. Clark						0					23	0	2.3			F.
216	Brunswick							0					5	tr.				F.
217	Do.		Paradise	17		0.6		0.05	0.8	0.3	2.7	0.3		7.1	0.6	4.9		Henry Carmichael.
218	Do.	do	do	18	0.3	6.6		0.09	0.7	0.3	0.3			1.0	1.0	4.2		F. C. Robinson.
219	Falmouth Foreside	Underwood Spring Corporation.	Underwood	36	0	8.6			3.2	0.7	5.9	0.9		1.1	9.1	6.8		F. L. Bartlett.

220	Harrison		Summit		4.1	17	tr.	tr.	6.8	1.2	11			7.4	1.9	27			Do.
221	New Gloucester	Pownal Spring Hotel Co.		20	0.2	7.0		0.3	2.2	0.1	2.0	0.2		8.2	1.6	5.0			F. C. Robinson.
222	North Raymond	Raymond Spring Co.	Raymond	[k] 34	tr.	7.2		0.03	6.8	1.1	1.6	0.6	0.1	0.8	2.4	13			W. F. Haines.
223	Saco		Cascade	30	22										3.0			9.5	State board of health.
224	Scarboro							0					49	[l]	14				F
225	South Freeport	G. W. Soule			2.2			tr.	tr.					tr.	0.5			1.7	Ohler.
	Franklin County:																		
229	Carrabassett	Carrabassett Mineral Spring Co.	Carrabassett			12		0.42	5.7	1.7	1.0	0.8		4.1	1.7	11			S. P. Sharples.
230	Do	do	do	72		14	5.3	3.7	8.2	4.3	2.8	1.6		1.6	4.4	15			Salvatore La Bua.
231	Do	do	do	26		1.0	5.7		2.5	1.3	1.4	1.0		5.7	3.3	3.6			Do.
232	Do	do	do	38		12	0.6		6.0	1.6	1.0	0.5		4.1	1.7	10			S. P. Sharples.
233	Farmington Falls	Farmington Falls Aqueduct Co.						0					9	tr.					F
234	Rangeley	Rangeley Lakes Hotel Co.	Rangeley Mineral	58	12	12	tr.		7.8	2.0	1.2			12	1.9	9.3			F. R. Stillman.
235	South Strong	R. W. Knowlton	Knowlton's Soda	42		16	[m] tr.	tr.	2.1	0.7	4.3	3.4		4.3	2.7	8.6			H. L. Bowker.
	Hancock County:																		
236	Bluehill	Bluehill Mineral Spring Co.	Bluehill Mineral	[n] 79		21	[m] 1.0	3.1	12	1.7	3.9	0.51		7.6	3.1	23			
237	Do	do	do	[o]		21	[m] 1.0	3.2	12	1.8	10			7.6	6.7	3.6			W. P. Mason.
238	Eastbrook	R. B. Lowrie	Katagudos	20		7.3	0.2		1.6	0.5	1.8				2.7				J. W. Baird.
239	Mount Desert		Mount Desert	64	20	9.4	tr.		10	1.6				1.6	10			32	Davenport & Williams.
240	Stonington							0					29	0	13				F
241	Tremont												22	tr.	95				F
242	West Hancock		Ishka	16		6.4		0.1	1.2	0.5	1.4			1.4	2.4	2.2			H. Carmichael.
	Kennebec County:																		
243	Augusta	C. O. Cony						0					5.0	tr.	21				
244	Chelsea	W. H. Austin						0				79		tr.	59				
245	Do					8.8			2.3	0.5	3.3	1.8		1.1	4.4	4.7			
246	Clinton (Morrison Corner).	H. E. Kendall		33														41.23	

[a] F, field assay by F. G. Clapp, G. C. Matson, or B. L. Johnson.
[b] At 120° C. Include phosphate radicle, 0.95. Lithium, none; bromine, none; iodine, none.
[c] Silica and alumina, 15.
[d] Analysis probably incorrect.
[e] For full analysis see p. 99.
[f] Al, 2.4.
[g] For full analysis see p. 97.
[h] Also nitric acid radicle (NO_3), 5.89; nitrous acid radicle (NO_2), 0.0032; PO_4, trace; metamoric acid radicle (BO_2), 0; arsenic acid radicle (AsO_4), 0; Br, 0; iodine, 0; Mn, 0; L, minute traces; ammonia (NH_3), 0.008; gases (cubic centimeters per 1,000 grams at 0° C. and 760 millimeters pressure) free CO_2, 5.6; CO_2 (set free from bicarbonates on evaporation to dryness), 8.8.
[i] For full analysis see p. 101.
[j] Al, 22.0.
[k] Include aluminum (Al), 0.02; phosphate radicle (PO_4), 0.04; borate radicle (BO_4), 0.10.
[l] SO_4 less than 35 parts per million.
[m] Al.
[n] Include nitrate radicle (NO_3), 0.58; manganese (Mn), 0.25.
[o] Include nitrate radicle (NO_3), 0.66; manganese (Mn), 0.22.

Analyses of spring waters in southern Maine—Continued.

No.	Locality.	Owner.	Name of spring.	Total solids.	Organic and volatile matter.	Silica (SiO_2).	Iron and aluminum oxides ($Fe_2O_3 + Al_2O_3$).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Carbonate radicle (CO_3).	Total hardness as $CaCO_3$.	Analyst.
	Kennebec County—Continued.																	
247	Litchfield	Forest Springs Water Co.	Forest No. 1	[a]100	3.0	14	.....	tr.	22	1.6	5.3	2.7	.....	9.0	3.0	38	....	
248	Do.	do	Forest No. 2	[a]55	3.3	14	.....	.....	8.8	1.5	3.8	0.8	.....	.....	2.8	38	....	
249	Do.	do	Forest No. 3	[a]28	3.0	9.5	.....	.....	2.1	0.5	2.7	0.6	.....	1.1	2.2	6.1	..	
250	Togus		Hallowell	.....	6.3	15	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	....	
251	Vienna		Vienna Sparkling	51	0	8.2	0.9	.....	13	1.5	0.1	1.9	.....	2.4	0.2	23	....	C. F. Chandler.
252	Do.		do	[a]43	0	15	tr.	.....	4.4	1.0	5.3	0.4	.....	0.0	0.1	16	....	S. D. Hayes.
253	Winslow		Ticonic Mineral	185	.....	11	tr.	5.8	42	9.9	19	5.0	.....	2.2	5.0	70	....	S. K. Hitchings.
254	Do.			.....	.....	.....	.....	0	.....	.....	.....	.....	43	(b)	9.4	.....	....	F.
255	Knox County: Rockland, in bottom of limestone quarry.			234	28	15	8.9	.....	20	22	20	4.7	.....	29	6.1	....	....	F. C. Robinson.
	Lincoln County:																	
256	East Boothbay		Boothbay Medicinal.	212	.....	11	[c]tr.	20	14	2.9	13	15	89	28	19	.....	....	E. L. Bartlett.
257	Jefferson			86	.....	16	.....	0.3	14	3.4	5.0	3.6	.....	7.4	5.5	31	....	F. C. Robinson.
258	Nobleboro		Samoset Mineral	425	tr.	12	....	19	23	1.9	13	.....	.....	37	11	192	....	H. C. Carmichael.
	Oxford County:																	
259	Hartford	Consolidated General Mineral Water Co.	Mount Hartford Mineral.	[d]36	.....	8.5	[c]0.1	0.4	3.2	0.7	4.2	0.6	.....	4.0	1.1	9.0	....	J. W. Mallett.
259a	Do.	do	do	46	.....	9.0	.....	.....	4.4	1.0	4.0	0.8	20	1.6	4.0	.....	....	W. W. Skinner.[e]
260	Milton plantation	Mount Zircon Spring Co.	Mount Zircon	33	2.2	9.7	[c]tr.	0.7	2.3	.....	1.0	9.8	.....	5.4	1.5	.....	....	E. L. Bartlett.
261	Paris	Paris Hill Water Co.	Crocker Hill (public supply) No. 1.	[a]11	3.7	1.2	0.3	....	0.5	tr.	1.8	.....	.....	.....	3.9	.....	....	
	Do.	do	Crocker Hill (public supply) No. 2.	[a]13	2.1	1.7	0.4	....	0.5	0.1	2.3	.....	.....	.....	3.6	.....	....	
	Do.	do	Crocker Hill (public supply) No. 3.	[a]14	2.7	1.8	0.5	....	0.6	0.2	2.5	.....	.....	.....	3.9	.....	....	
262	Do.		Mount Mica Mineral.	.....	.....	.....	.....	0	0	.....	.....	.....	10	.....	2.2	.....	....	F.
263	Rumford Falls	Rumford Falls Power Co.	Cataract	.....	.....	.....	.....	.....	.....	.....	.....	.....	22	tr.	4.9	.....	....	F.
264	Sumner	United Mineral Springs Co.	Mount Oxford	3.4	.....	8.0	.....	2.1	6.6	0.3	1.5	.....	.....	1.4	2.5	11	....	E. E. Calder.

265	Zircon		Zircon Moon Tide	26		9.0	0.1		2.1	0.6	3.1			3.9	0.8	6.1		S. P. Sharples.
	Penobscot County:																	
266	Brewer	A. H. Farrington	Highland	16		tr.	tr.	tr.	0.8	1.2	4.0			tr.	6.0	4.4	15	O. W. Knight.
267	Do	M. W. Staples						0					157	tr.	7.3			F
267a	Do	Miss Jennie Farrington	Oak Grove	136		16			18	3.5	7.0	1.1	73	4.9	5.6			W. W. Skinner.[g]
268	Orrington	A. G. Dole	Sparkling	194	16	[h] 11		0	14	1.5	41	12		29	60	17		Richard Pfliffar.
	Sagadahoc County:																	
269	Topsham	Pine Spring Water Co.	Pine	13		4.6		0.33	1	0.03	2			0.2	2.3	3.1		F. C. Robinson.
270	Do	do	do	33		7.4			2.1	0.8	3.5	0.6	13	1	4.2			W. W. Skinner.[o]
	Somerset County:																	
271	Fairfield	W. N. Osborne	Rocky Hill	63	54	11			11	3.7	2.1	0.4		2.9	2.5	24		F. C. Robinson.
271a	Do	do	do	106		11			13	4.3	4.6	.8	64	3.7	2.8			W. W. Skinner.[i]
272	St. Albans	C. A. Moulton	Glenwood	67		3	[c] 1	1.4	10	10						40		S. S. Bradford.
272a	Do	do	do	94		11			13	2.5	3.9	.9	55	3.6	1.8			W. W. Skinner.[j]
273	Skowhegan	West Skowhegan Aqueduct Co.						0					10	0	10			F
	Waldo County:																	
274	Prospect	Switzer Water Co	Switzer	376	tr.										50		(k)	F. C. Robinson.
	Washington County:																	
275	Addison	Addison Mineral Spring Co.	Addison Mineral	139		tr.		8.9	14	2.2	9.6	4.6	76	15	9.2			S. D. Hayes.
276	Do	do	do	135		tr.	[c] tr.	8.9	14	3.2	9.5	2.6	75	13	9.2			Do.
277	Calais							0					16	tr.	6.3			F
278	Columbia	Quantabacook Water Co.	Harrington (public supply).	70	12	13	1.2		17	1.8	6	1.1		6.5	9			F. C. Robinson.
279	East Machias	Estate of Peter Talbot.						0	0				18	0	4.6			F
280	Eastbrook	R. B. Lowrie	Katagudos															
281	Lubec	Lubec waterworks	Lubec (public supply).					0					66	([b])	13			F
282	Do	Town of Lubec	do	102	7	11		0.4	20	3.2						39		F. C. Robinson.
282a	Head of Lubec Bay		Lubec Saline	4,609	[l] 181			17	83	228	1,250			390	2,388	72		C. T. Jackson.
283	Millbridge	Millbridge Water Co.						0					11	([b])	8.8			F
284	Terry							0					111	([b])	23			F
	York County:																	
285	Kennebunk	Heirs of Chas. Parsons.						0					24	([b])	19			F
286	Kennebunk Beach		Kennebunk Beach Mineral.	189														S. H. Hitchings.
287	Limington	G. P. and Frank Anderson.	Cold Bowling	27	11	3.2			1.4	0.2	3.5			1.1	0.9	5.9		
288	Ogunquit	C. W. Dunyon	Wawa Lithia	([m])		2		tr.	3.7	1.1	1.8	1.6		3.2	12	12		A. E. Austin.
289	Old Orchard	Olde Yorke Springs Co	Olde Yorke	94		4.2		0.6	14	3.5	11	5.8		8.2	12	34		F. C. Robinson.
289a	Scarboro		Scarboro Mineral	[n] 3,190	18				30	114	1,025	27		72	1,763	141		Geo. L. Goodale.
290	Springvale	Geo. G. Plummer	White Sand	42	12			0.01							0.2		20	

[a] Include lithium (Li), trace.
[b] SO_4 less than 35 parts per million.
[c] Al.
[d] Include manganese (Mn), trace; strontium (Sr), trace; rubidium (Rb), trace; lithium (Li), 0.01; phosphate radicle, 0.02.
[e] For full analysis see p. 181.
[f] Nos. 1 and 2 from reservoir. No. 3 from residence of Geo. M. Atwood, at Paris.
[g] For full analysis see p. 195.
[h] With Al_2O_3.
[i] For full analysis see p. 208.
[j] For full analysis see p. 207.
[k] Temporary, 25.9; permanent, 16.
[l] Includes $CaCl_2$.
[m] Include lithium (Li), 3.
[n] Include Br, trace.
[o] For full analysis see p. 201.

Total solids.—The total solids constitute the residue left on evaporation of a water sample. Those reported in southern Maine well and spring waters range from 13 parts per million in a spring at Naples to 4,055 parts in a well at North Haven. The high percentage of mineral matter in the North Haven water and in several other wells near the sea which show abnormally high solids is generally due to an admixture of ocean water that penetrates inward along joint cracks in the rocks. With one exception, the highest amounts of total solids in southern Maine which are believed to be due to the natural composition of the water are somewhat under 500 parts per million and are found in several widely scattered wells drilled in slate in Penobscot and Somerset counties. The minimum of total solids in slate is 52 in a well at Portland. The figures in Aroostook County slates (and "slated limestones") in northern Maine are higher, ranging between 200 and 800 parts per million. A single well at Bangor reports 834 parts per million.

In granite one well at North Sullivan reports 364 parts per million, and one in Waldoboro 419 parts. These figures are high for granite, as the total solids in granite waters generally run below 200. Most springs issuing from sand and gravel give low figures, many running below 30. One spring, at South Freeport, reported only 2.8 parts per million of total solids, but this figure is probably wrong.

The reports of the State board of health contain many sanitary analyses which show the amount of total solids in spring waters, but as the springs are mostly private ones, and as the material from which they issue is not known, or known only through correspondence, the analyses would be of little value in this report, and only two or three are given.

Organic and volatile matter.—Organic and volatile materials are much greater in amount in the waters analyzed than might be expected in deep-well and spring waters. It should be noted, however, that some of the highest figures occur in analyses for which the name of the chemist is not known, and hence their accuracy is open to doubt. Normally, with a few exceptions, the organic and volatile matter ranges from 5 to 100 parts per million in wells, and from 0 to 30 parts in springs. An exceptionally large amount of "organic and volatile matter" may be due to pollution of the water, to water of crystallization, or to volatile mineral components.

Silica.—The amount of silica in Maine waters is always low. As shown by the diagrams, it ranges from 7 to 25 parts per million for well waters, exclusive of the wells where it can be attributed to sea water. In spring waters the silica runs from 0.24 part to 21 parts. The highest amount, 21 parts, occurs in the Blue Hill Mineral Spring.

Iron and aluminum oxides.—The figures for iron and aluminum oxides are much more constant than those for any other ion or group

of ions. With the exception of iron when reported alone, they are the lowest of all the materials commonly estimated. (See lowest line in Pls. IV, VI, and VIII.) In well waters from granite and similar rocks these minerals run from 1 to 8 parts per million; in those from sand and gravel, 1 to 2 parts; in spring waters, 0.2 to 9 parts. The highest amounts occur in spring water from a limestone quarry at Rockland.

Iron.—Most of the analyses reporting iron separately from aluminum are field assays, and in them iron is generally found to be absent. Most Maine waters are destitute of iron in appreciable quantities. As half a part per million of this mineral is recognizable to the taste, it will be seen that much iron would make the waters unusable. The greatest amount reported, 5 to 10 parts per million, is in the wells of the Northern Maine Seaport Railroad Company in Waldo County. This amount of iron in a water would make it undrinkable; hence it is probable that the figures given for iron in these wells may include alumina.

A number of mineral springs also report high iron, and to some of these the statement just made may possibly apply. As a rule, the amount of iron in springs of this State runs below 1 part per million. The Blue Hill Mineral Spring, which is said to issue from a rock containing a large quantity of iron, contains only 3.2 parts per million of this mineral.

Calcium.—Calcium, a constituent of lime, is one of the most abundant ingredients. It is generally highest in limestone, and runs from 40 to 160 parts in the areas of calcareous slates. Exceptional figures are much higher. The lowest known figure for calcium in slate water is 4. In granite it ranges from 1 part per million in a well on Greenings Island to 62 parts in a North Sullivan well. In gravel waters the amount is from 3 to 6 parts. In springs it ranges from a mere trace to 42 parts.

Magnesium.—In waters where calcium occurs magnesium also is found, but generally in much smaller quantities. In granite waters it ranges from 2 to 10 parts per million, in slate from 1 to 30, and in sand and gravel from 1 to 5. In calcareous slates in northern Maine the amount of magnesium runs from 15 to 40 parts. In spring waters the amount of this element is very uncertain, running as high as 14 parts, but being in most springs below 3. The analysis of limestone water from Rockland shows 22 parts of magnesium, nearly as many as of calcium—29. In two analyses, those of the Highland Mineral Spring at Lewiston and the Keystone Mineral Spring at Auburn, magnesium without calcium is reported. This is evidently a mistake, and it is possible that part of the solid matter reported as magnesium is in reality calcium.

Sodium. Sodium is one of the constituents of common salt and of sea water, which explains why it is so high in certain analyses. Normally it runs from 7 to 60 parts per million in granite, from 3 to 30 parts in slate, and from 1 to 10 parts in gravel. In spring waters it is variable, but seldom exceeds 20 parts. In most Maine waters sodium is much lower than calcium, as shown by the diagrams. In sea water, however, sodium far exceeds calcium and magnesium in amount. The fact that in analysis No. 155 calcium is much in excess of sodium indicates that perhaps the high total solids may not be due entirely to sea water, as would appear at first inspection of the diagram.

Potassium.—Smaller quantities of potassium than of sodium are found in most waters. The element is usually in equilibrium with chlorine, as is sodium, and it is also found in sea water. In granite the amount ranges from 0.5 to 13 parts per million, in slate from 0.8 to 17, and in sand and gravel it is below 3. In two well waters the amount of potassium is reported greater than that of sodium. In spring waters it runs from 0.2 to 15 parts.

Bicarbonate radicle.—All carbonates occurring in Maine well and spring waters are believed to exist in the bicarbonate or acid-carbonate form, as several hundred tests for the normal or alkaline carbonate resulted negatively. The figures in the bicarbonate radicle column are mostly the results of field assays made according to the standard method of the United States Geological Survey,[a] and are approximate only. The tests made show the amount of bicarbonates to range from 9 to 143 parts per million in granite, 20 to more than 500 in slate, 40 to 167 in clay, 16 to 80 in bowlder clay, and 10 to 128 in sand and gravel. One report from a well in slate gives 765 parts per million. The higher figures, while somewhat scattering in distribution, are mostly from the northeastern quarter of the State. In Aroostook County none of them are under 100 and many exceed 300 parts per million. In spring waters the bicarbonate radicle is generally low, one refined analysis showing only 0.14 part. In a few springs the bicarbonates exceed 100 parts per million.

Carbonate radicle.—Most of the analyses of spring waters and a few analyses of well waters made by chemists not connected with the United States Geological Survey report calcium, sodium, and other carbonates. There is no way of determining from these analyses what proportion of the carbonates exist in the form of the normal carbonate radicle and what proportion in the bicarbonate form. In recomputing the results, therefore, it has been necessary to express them simply as "carbonate radicle" (CO_3), though these are probably all bicarbonates (HCO_3). Although normal carbonates are not known

[a] Leighton, M. O., Field assay of water: Water-Supply Paper U. S. Geol. Survey No. 151, 1905, pp. 66-69.

to have been found in Maine waters, they can not be said with certainty to be absent.

Sulphate radicle.—All sulphates occurring in Maine waters have been recomputed to the sulphate radicle (SO_4). Small amounts of this compound occur in most waters, and in some they are high. In granite they range from a mere trace to 36 parts per million, in clay from 0 to 53 parts, and in gravel and sand from 0 to 11 parts. In spring waters the sulphates range from 0 to 37 parts, but are generally below 10.

Chlorine.—Chlorine, a constituent of common salt, is one of the most variable components of natural waters. It ranges in the Maine waters analyzed from less than 1 part per million to as high as 1,790 parts in one well which was invaded by sea water. The highest chlorine that is believed to be due to the composition of the rock is somewhat under 200 parts. In some portions of the country (as in places in New York State), where the rocks contain salt, however, the waters are high in chlorine. Normal chlorine lines and the limitations of their use are explained on pages 27–28. In the majority of well waters the chlorine is above the normal as given for the local surface waters. In most deep wells which are properly cased this is due to chlorine dissolved from the rocks and in open wells to the entrance of surface waters.

Hardness.—The hardness of waters may be classed as temporary, due to the carbonates and bicarbonates of calcium and magnesium; or permanent, due to sulphates, chlorides, or nitrates of the alkali earths. A large part of the hardness in Maine waters is temporary and can generally be removed by boiling, which precipitates the hardening constituents. Aside from the analyses made by the state board of health, few tests for hardness have been made. In general the waters outside of Aroostook County and parts of Penobscot and Somerset counties are soft; and when they are described by residents or in the table at the end of the report as "hard" the term is used only relatively, with reference to softer waters in the same region. The total hardness of waters in southern Maine ranges up to 300 parts per million, the highest figures being shown in Penobscot County, where the rocks are slightly calcareous. The hardness of spring waters, however, seldom exceeds 20 parts. The reports of the state board of health include several hundred analyses of spring waters which give the hardness. Few of these are published here, as the material from which the spring issues is known only through correspondence.

Lithium.—Few tests for lithium in Maine waters have been made. One or two well waters which issue from granite report traces of this element, and amounts up to 0.01 part per million are reported to have been found in spring waters issuing from granite and gneiss.

Other substances.—In a few analyses tests have been made for other elements. Manganese, strontium, rubidium, phosphates, arsenates, and borates have been found as mere traces. Tests for bromine and iodine have resulted negatively. None of the substances mentioned have been found in quantities large enough to give the water medicinal properties. The most complete analyses, showing something in respect to the probability of finding the rarer elements in spring waters, are those made by the Bureau of Chemistry, United States Department of Agriculture.

DESCRIPTION OF UNDERGROUND WATERS BY COUNTIES.

ANDROSCOGGIN COUNTY.

GENERAL DESCRIPTION.

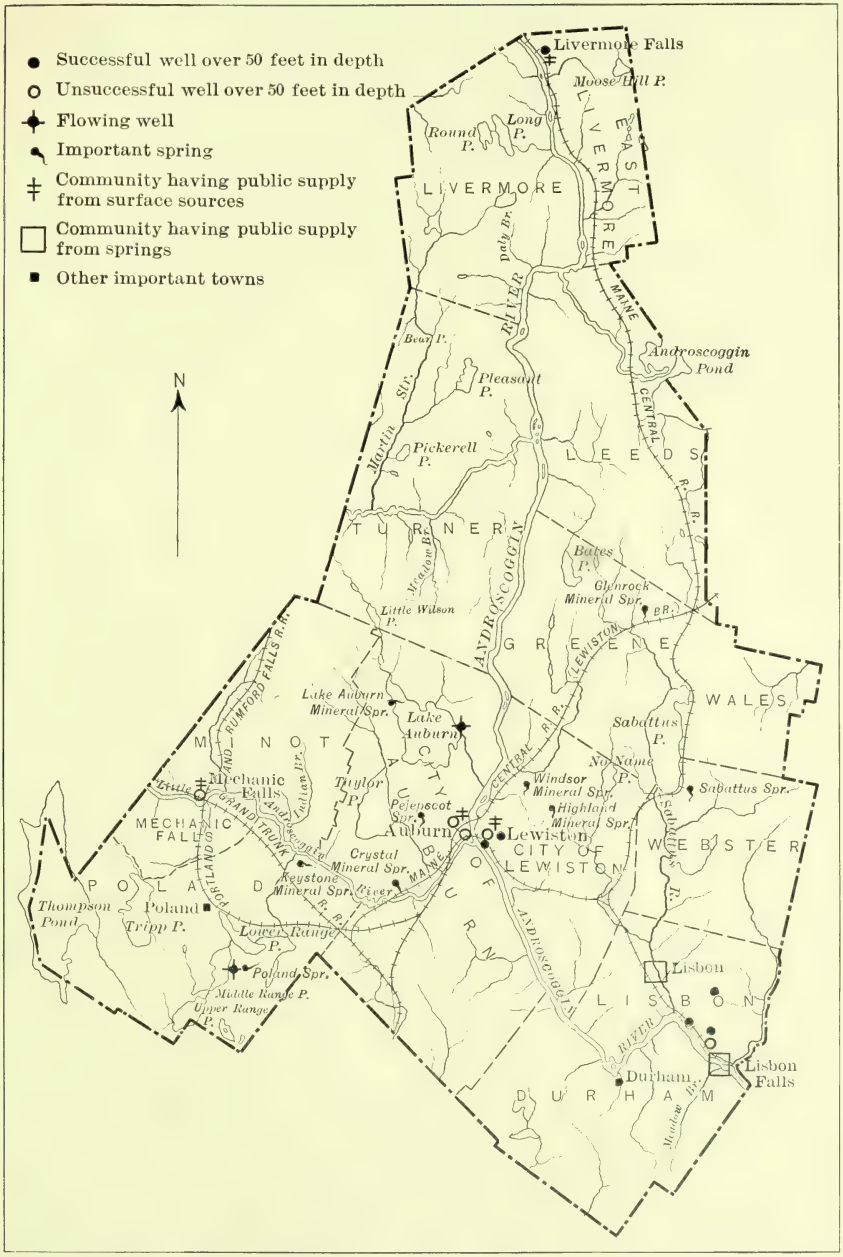
Androscoggin County is situated in the southwestern part of Maine, on both sides of Androscoggin River. It is one of the smallest counties in Maine, having a length of 40 miles, an extreme breadth of 25 miles, and a total area of only 480 square miles. The population, according to the census of 1900, was 54,242. Lewiston is the largest city, having a population of 24,997. Auburn, the county seat, on the opposite side of the river from Lewiston, contained 13,971 inhabitants. This county is moderately hilly, ranging in altitude from 100 to more than 800 feet.

UNDERGROUND WATERS.

RELATION TO ROCKS AND SURFACE DEPOSITS.

Distribution of rock types.—The rocks of Androscoggin County consist for the most part of complex intrusions of granite and gneiss in schist, but a strip along the eastern border of the county, north of Lisbon, is underlain by slate. In the vicinity of Lewiston and Auburn the rocks consist mostly of hard gneissic schist or granitic gneiss, cut by small granite dikes. In most places within this strip the rock is distinctly bedded, but the strike and dip are extremely variable, the strata being much contorted in places. In some localities the joints are open and the rock is decomposed, allowing penetration of water downward; in other places the rock is dense, and all the cracks are tightly closed. This probably accounts for the failure of several deep wells at Auburn and Lewiston. Farther away from the boundary of the slate area, and in some places near its border the rock is true granite. A map of Androscoggin County showing the distribution of deep wells, important springs, and communities having public water supplies forms Pl. XI.

Surface deposits.—The greater part of the uplands of the county is covered by bowlder clay and irregular gravel deposits, locally of



MAP OF ANDROSCOGGIN COUNTY.

Showing distribution of deep wells; important springs, and communities having public supplies.

considerable thickness. Along the rivers, however, rather extensive lowlands consist of clay rising to a maximum elevation of about 200 feet. At Lewiston a number of brickyards make use of this clay. At Lewiston Upper Station the clay is 20 feet thick and in places is overlain conformably by stratified sand and underlain by coarse gravel. In other parts of Lewiston the clay is more than 30 feet in thickness. Gravel underlies the clay in the vicinity of Lisbon Falls and Lewiston, and probably nearly everywhere in the Androscoggin Valley. Many flat sand and gravel deposits extend along the valley of Little Androscoggin and other rivers and surround the principal lakes and ponds. The total thickness of these deposits varies greatly, but in extreme cases along the valleys it is as much as 60 feet. On the highlands the drift is thinner, generally not more than 5 to 15 feet thick.

WELLS.

GENERAL DESCRIPTION.

Types of wells.—The majority of the wells of Androscoggin County are open surface wells, but some driven wells are used, and in Lewiston, Auburn, and Lisbon Falls there are a few drilled wells. The open and driven wells vary in depth from 10 to 35 feet, and in the valleys they are generally successful, so far as the quantity of water is concerned, although some have been dug to rock without success, and the water in many of them becomes very low or gives out in a dry season. In general dug wells are the only type of shallow wells which can be used on the hills, but driven wells are more satisfactory in the sands and clays of the valleys.

Drilled wells.—In parts of the county where it is not possible to obtain water of suitable quality or in sufficient quantity from surface wells drilling should be adopted. Little drilling has been done as yet, but the method will be used more and more in future. Some hesitation may be felt in regard to it at Lewiston and Auburn because several of the wells, including one 654-foot well, have been failures. It is possible that in this vicinity open joint cracks containing water are so rare and superficial that successful wells can not be obtained; but the region has hardly been fairly tested, and it is possible that in some parts of these cities there may be plenty of water in the rocks. If tests are made, it will probably not pay to drill below 300 feet. Most of the wells already sunk have been 6-inch wells, but one 8-inch well was drilled. The depths range from 50 to 654 feet.

Quality of water.—Little can be said in regard to the quality of water in Androscoggin County, as few analyses have been made. Field assays of the water from dug wells at Auburn and one at Mechanic Falls show a very low mineral content. A drilled well in

granite at South Poland gave 98 parts per million of total solids. A well in Auburn, location not known, reports 112 parts per million of total solids. Throughout the county the water is soft, but in drilled wells it is less so than in the surface wells. In nine springs, the waters of which have been analyzed, the total solids range between 29 and 154 parts per million. In one driven well and one drilled well the water is said to overflow the surface.

Uses.—In all parts of the county the chief use of well water is for domestic and farm purposes, and it is seldom used for anything else. At Lewiston, however, water from gravel is used in Bates's mill for bleaching purposes.

DETAILED DESCRIPTION.

Lewiston and Auburn.—At Lewiston and Auburn wells drilled in the solid rock have generally been failures. A well of the Standard Dry Plate Company, corner of Bates and Pine streets, Lewiston, found very little water. A well belonging to Mr. John Picket, now deceased, on Highland street, Auburn, got water, but is now abandoned. One of the most conspicuous failures in Maine is a well belonging to the Turner Center Creamery in Auburn. This well was drilled by an experienced driller to a depth of 654 feet, but absolutely no water was found below 8 feet from the surface. The first 90 feet was through gravel and clay, the rest in gneiss. The quality of water, where found, is generally good. Analyses of well waters in Auburn are given in the table on pages 82, 83 (Nos. 175 and 196).

The plant at Bates's mill, Lewiston, consists of 15 driven wells ranging in depth from 30 to 40 feet. The formation at the mill consists of 20 feet of gravel ("made ground") resting on about 5 feet of clay, below which lies 2 feet of gravel containing a plentiful supply of water. The gravel bed slopes to the south and appears at the bottom of all these wells and also at the bottom of a 65-foot well owned by the same company, situated 200 feet beyond the last well of the system. The water tastes strongly of iron. It is used in bleaching, and the pumps are run fifteen hours a day, pumping an average volume of 350 gallons a minute.

Dug wells are far more common than driven wells in this vicinity, and, except in the clay areas, are generally of moderate depth and are fairly satisfactory if protected from pollution. In the clay areas wells should be driven or drilled through the clay into the underlying sand and gravels, which generally contain plenty of water. Some open wells are blasted in rock, the chief value of this method being to furnish a reservoir for the water of the overlying drift. At North Auburn there are a few dug wells 40 to 60 feet in depth, most of them many years old. Several drilled wells are reported within the town

limits. A few dug wells and springs are pumped by windmills. In the southern part of the town there are considerable areas of sand plain in which water can be easily obtained at shallow depths. Dug wells have been used mostly thus far, but some persons are now using driven wells. Several commercial mineral springs are situated in these towns and will be described under the appropriate heading. (See pp. 96–99, 103.) The public supply of Auburn and Lewiston is taken from Lake Auburn. This would be excellent water if properly protected, but unless the building of cottages and pleasure resorts on the lake shores is regulated and boating is stopped the supply will soon become dangerous for drinking.

Poland.—The conditions in the town of Poland vary greatly. Considerable areas in the eastern part of the town and in the vicinity of the ponds consist of sand and clay plains, but a large part of the town is hilly. Open wells are the rule, being generally dug to bed rock, and some of them are blasted into the rock itself as much as 4 to 10 feet. Only one drilled well is known. This is situated 700 yards from Poland Spring and was drilled in granite in the hope of tapping the spring supply. Needless to say, the attempt failed. The analysis of water from this well is given in the table (No. 2).

Mechanic Falls.—A number of years ago test wells were sunk at Mechanic Falls to depths of 30 to 60 feet through clay and fine sand, in order to get a public supply. A little water overflowed the surface, but the amount was too small, so the wells were abandoned. As the village lies on broad clay and sand plains bordering Little Androscoggin River, the water is here abundant and is easily obtained by dug and driven wells. The water is obtained on top of the clay, but if this is penetrated a more abundant supply of better quality will be found. It is possible, even, that flowing wells may be obtained in places. Driven wells are recommended in preference to dug wells wherever practicable, but all forms of wells should be sunk through the clay.

Lisbon.—Along the river at Lisbon water is found in shallow wells in sand resting on clay. Several wells drilled in granite at Lisbon Falls were sunk to depths ranging from 50 to 187 feet, and all but one were successful as regards quality of water. Only one field assay (No. 1 of the table) is available to show the mineral content of the water here.

East Livermore.—At Livermore Falls one or more shallow drilled wells have been sunk, but no information is at hand regarding them.

Other towns.—In the towns of Danville, Minor, Webster, Wales, Greene, Turner, Leeds, and Livermore no wells are known to have been drilled, the type generally in use being the ordinary open wells used at most farmhouses.

SPRINGS.

General statement.—Commercial mineral springs are more abundant in this county than in any other county of Maine, no fewer than seven springs reporting sales of water being situated within its borders. These are as follows:

Crystal Mineral Spring, Auburn.
Highland Mineral Spring, Lewiston.
Keystone Mineral Spring, East Poland.
Pejepscot Spring, Auburn.
Poland Spring, South Poland.
Sabattus Springs, Sabattus.
Windsor Mineral Spring, Lewiston.

In addition to these there are several other springs of interest, the water of which is not sold.

Crystal Mineral Spring.—The Crystal Mineral Spring is owned by the Samoar Carbonating Company, of Lewiston. It is situated on a sloping hillside 3 miles southwest of Auburn depot, and the water issues from undulating deposits of stratified sand, known as kames, which rest on a bed of clay. The water is collected in a cement-lined and glass-covered masonry tank, about 8 feet square and 4 feet deep, inclosed in a spring house where the water was formerly bottled. It is now hauled to Lewiston and bottled there, being mostly carbonated for soda water and ginger ale, and sold under the trade name Samoar water. The temperature of this water at the spring is 47° and the measured overflow is 6 gallons a minute. The water has no color, odor, or taste, and on account of its situation distant from houses there is no chance for pollution. The analysis, recomputed from that given in the circular issued by the owner, is given in the table (No. 203a).

Glenrock Mineral Spring.—The Glenrock Mineral Spring is situated in the town of Greene, 2½ miles south of the post-office. It is owned by A. B. Parker & Sons, of Greene. The water issues from gravel deposits on a gentle slope in an open field. The spring is incased in granite curbing cemented to an impervious stratum, and is reported to flow 18 gallons a minute, not varying according to season. The temperature is 47½°. The water is colorless, odorless, and tasteless, and is of excellent quality. It is used as a table and medicinal water by many families in Lewiston and Auburn. The analysis of the water is given in the table (No. 206b), the composition being taken from the circular issued by the owners and recomputed according to the standard method.

Highland Mineral Spring.—The Highland Mineral Spring is situated on a southward-sloping hillside in the city of Lewiston, about 3 miles northeast of the post-office. It is owned by the Highland Spring Water Company, of New York. The hill on which the spring is

situated is composed of gneiss and schist cut by pegmatite dikes, and a covering of 1 to 5 feet of bowlder clay overlies the rock. The water occurs in a vertical 6-inch crack parallel with the stratification of the gneiss, entering from the direction of the summit of the hill on the north side of the spring. The water is believed to be derived from the rain and snow falling on the hillside within a few hundred feet of the spring, being held in the drift and the upper crevices of the rock until it emerges at the spring. The spring is reported to flow 20 gallons a minute in a wet season, but diminishes somewhat during the summer. The temperature averages 42°, varying a little during the year.

The spring is inclosed with a granite curbing, and the whole is covered with a small spring house. The bottling house is 50 feet away. The situation is almost ideal for a mineral spring, as the hill rises 100 feet or so above it and is covered mostly by thick woods. There are no houses on the hill except two cottages on the summit, several hundred yards from the spring, separated from it by a small ravine. These are occupied for a month in summer by the treasurer of the company—a prominent New York physician—and as every precaution is taken in respect to drainage, there is practically no danger of the spring water becoming polluted. The water is bottled near by and shipped to New York and other cities. Valuable medicinal properties are claimed for it by the owners. The water retails in New York for $2 a 5-gallon carboy, or the same rate for a case of 12 quarts. This is colorless, odorless, and tasteless.

Several analyses have been made of this water (Nos. 209, 210, and 210a of the table), but the most complete is that made by W. W. Skinner, of the Bureau of Chemistry, United States Department of Agriculture, in connection with cooperative work on mineral waters conducted by the Geological Survey and the Bureau of Chemistry. The proportions of the various constituents are as follows:

Analysis of water from Highland Mineral Spring.

[W. W. Skinner, analyst.]

Gases (cubic centimeters per 1,000 grams at 0° C. and 760 mm. pressure):	
Carbon dioxide (CO_2), free	38.2
Carbon dioxide (CO_2), set free from bicarbonates on evaporating to dryness	4.2
	Parts per million.
Phosphoric acid radicle (PO_4)	None.
Metaboric acid radicle (BO_2)	None.
Arsenic acid radicle (AsO_4)	None.
Silica (SiO_2)	11.40
Sulphuric acid radicle (SO_4)	4.65
Bicarbonic acid radicle (HCO_3)	22.90
Nitric acid radicle (NO_3)	None.

	Parts per million.
Nitrous acid radicle (NO_2)	None.
Chlorine (Cl)	2.20
Bromine (Br)	None.
Iodine (I)	None.
Iron and aluminum (Fe and Al)	.35
Manganese (Mn)	None.
Calcium (Ca)	5.86
Magnesium (Mg)	.94
Potassium (K)	1.21
Sodium (Na)	2.79
Lithium (Li)	None.
Ammonium (NH_4)	.021
Oxygen to form Fe_2O_3 and Al_2O_3	.....
	52.321
Free ammonia	.02
Albuminoid ammonia	.05
Nitrogen as nitrates	Traces.
Nitrogen as nitrites	None.
Oxygen consumed	1.50

Keystone Mineral Spring.—The Keystone Mineral Spring is owned by E. H. Pratt, of East Poland. The spring is situated on a gently sloping hillside in the eastern part of the town of Poland, about a mile north of Empire Road station on the Grand Trunk Railway. The water issues from a nearly horizontal seam 4 feet or so from the surface, overlain by a bed of granite and underlain by gneiss. The beds of the gneiss strike N. 30° to 40° W. and dip 35° NE. The hill rises 10 feet higher within 100 feet southwest of the spring and 25 feet higher 200 feet north of the spring. To the east is a little valley; to the southwest lies an undulating sand plain a quarter of a mile in extent. The water apparently comes from the southwest, where it is caught on this sand plain, sinks into the underlying rock, and finds its way along the contact plane between the granite and the gneiss.

This spring is walled with a granite curb and inclosed in a bottling house, and is well protected from pollution. The temperature in the basin is 50°, the water being probably warmed somewhat by contact with the air. There is no color or odor and little, if any, taste. The measured overflow is a trifle over 3 gallons a minute and is reported to fluctuate very little with the weather or the season. The water has been analyzed, and the composition reported by the owners and recalculated into ions and parts per million according to the standard rules is given in the table (No. 206).

The best analysis of this water is one made by W. W. Skinner, of the Bureau of Chemistry, United States Department of Agriculture, in connection with cooperative work on mineral waters conducted by the Geological Survey and the Bureau of Chemistry. This analysis is as follows:

Analysis of water from Keystone Mineral Spring.

[W. W. Skinner, analyst.]

Gases (cubic centimeters per 1,000 grams at 0° C. and 760 mm. pressure:	
Carbon dioxide (CO_2), free	9.2
Carbon dioxide (CO_2), set free from bicarbonates on evaporating to dryness	10.9
	Parts per million.
Phosphoric acid radicle (PO_4)	None.
Metaboric acid radicle (BO_2)	None.
Arsenic acid radicle (AsO_4)	None.
Silica (SiO_2)	11.60
Sulphuric acid radicle (SO_4)	3.43
Bicarbonic acid radicle (HCO_3)	59.53
Nitric acid radicle (NO_3)	.88
Nitrous acid radicle (NO_2)	None.
Chlorine (Cl)	5.20
Bromine (Br)	None.
Iodine (I)	None.
Iron (Fe) and aluminum (Al)	.39
Manganese (Mn)	None.
Calcium (Ca)	14.72
Magnesium (Mg)	3.11
Potassium (K)	.84
Sodium (Na.)	4.23
Lithium (Li)	None.
Ammonium (NH_4)	------
Oxygen to form Fe_2O_3 and Al_2O_3	------
	103.93
Free ammonia	None.
Albuminoid ammonia	None.
Nitrogen as nitrates	.20
Nitrogen as nitrites	None.
Oxygen consumed	6.50

Keystone Spring water is bottled and mostly peddled in Lewiston and Auburn, but some is shipped by rail. Examination of the spring shows it to be probably secure from danger of pollution.

Pejepscot Spring.—Pejepscot Spring is situated on Golf Hill in Auburn, about 1½ miles northwest of the post-office. The water is reported by the owners to issue from a bed of sand near the base of the hillside. It is colorless, tasteless, and odorless, and is reported to flow about half a gallon a minute. It is put on the market for medicinal and table use. The analysis given in the table (No. 204) is recomputed from that furnished by the owners.

Poland Spring.—Poland Spring is the best-known spring in Maine. It is owned by Hiram Ricker & Sons (Incorporated) and is situated on Ricker Hill at South Poland. This is a hill of considerable size, rising 300 feet above the surrounding valley and consisting almost

entirely of granite and granite gneiss, covered only by 1 to 30 feet of hardpan or bowlder clay. On top of the hill stands the Poland Spring House, a famous summer resort.

On the north and east sides of the hill the formation is typical granite, but on the south and west slopes it is much more gneissic in character. The spring is situated on the east slope of the hill, 84 feet below the summit. In the immediate vicinity of the spring the rock is in few places more than 3 feet below the surface, and much of the surface is bare rock which slopes with the hill. The water issues from cracks in a dike of porphyry which is about 10 feet wide at the spring and strikes about N. 80° W., as nearly as can be estimated. This dike has been traced by the owners of the spring for a distance of 200 feet and its width diminishes at the southeast end to about 1 foot. Its other relations can not be determined without excavation, but it is reported to hade slightly into the hill. The spring itself is covered by a glass case and protected from too close intrusion by a marble wall surmounted by an iron grating. By looking down through the glass cover a number of narrow cracks a small fraction of an inch in width can be seen running parallel with the sides of the dike. The surface of the dike is weathered rather whitish and is somewhat decomposed. It is from this part of the dike that the water emerges.

No pains or expense have been spared by the owners of the Poland Spring to collect every available gallon of the water which emerges, and to protect the spring from all possible pollution. A trench was once excavated along the dike for many feet, and the dike covered with cement, to prevent the exit of water anywhere except in the spring. The curbing has been carefully cemented to the rock to prevent all surface wash, and over the spring has been built an elaborate and expensive marble spring house. The hotel stands on the summit of the hill several hundred feet distant, and all drainage from the hotel and stables is carried in tightly jointed pipes down the opposite slopes.

Poland water has no color, odor, or taste, and is very low in mineral matter, as shown by the analyses given in the table (Nos. 212, 213, 214, and 214a). The first and second analyses are reported by the owners of the spring and the various constituents have been recalculated into the ionic form and parts per million, according to the standard method.

The best analyses of the Poland Spring water were made by W. W. Skinner, of the Bureau of Chemistry, United States Department of Agriculture, in connection with cooperative work on mineral waters conducted by the Geological Survey and the Bureau of Chemistry. One of these, made in 1905, has been published,[a] but is repeated here.

[a] Haywood, J. K., Mineral waters of the United States. Bull. No. 91, U. S. Dept. Agr., Bur. Chemistry, 1906, pp. 52-53.

Analysis of Poland Spring water.

[W. W. Skinner, analyst.]

Gases (cubic centimeters per 1,000 grams at 0° C. and 760 mm. pressure):	
Carbon dioxide (CO_2), free	5.6
Carbon dioxide (CO_2), set free from bicarbonates on evaporating to dryness	8.8
	Parts per million.
Silica (SiO_2)	24.1
Sulphuric acid radicle (SO_4)	3.6
Bicarbonic acid radicle (HCO_3)	48.4
Carbonic acid radicle (CO_3)	.....
Nitric acid radicle (NO_3)	5.89
Nitrous acid radicle (NO_2)	.0032
Phosphoric acid radicle (PO_4)	Trace.
Metaboric acid radicle (BO_2)	None.
Arsenic acid radicle (AsO_4)	None.
Chlorine (Cl)	5.0
Bromine (Br)	None.
Iodine (I)	None.
Iron (Fe) and aluminum (Al)	.4
Manganese (Mn)	None.
Calcium (Ca)	13.9
Magnesium (Mg)	2.1
Potassium (K)	2.4
Sodium (Na)	6.9
Lithium (Li)	Minute trace.
Ammonium (NH_4)	.008
Oxygen to form SiO_3 and Fe_2O_3	1.2
	133.9012
Free ammonia	.008
Albuminoid ammonia	.051
Nitrogen as nitrates	1.33
Nitrogen as nitrites	.001
Oxygen required	.45

HYPOTHETICAL FORM OF COMBINATION.

	Parts per million.
Ammonium chloride (NH_4Cl)	0.024
Lithium chloride (LiCl)	Minute trace.
Potassium chloride (KCl)	4.6
Sodium chloride (NaCl)	4.6
Sodium sulphate (Na_2SO_4)	5.3
Calcium phosphate ($Ca_3(PO_4)_2$)	Trace.
Sodium nitrate ($NaNO_3$)	8.07
Sodium nitrite ($NaNO_2$)	.0048
Sodium bicarbonate ($Na(HCO_3)$)	4.4
Magnesium bicarbonate ($Mg(HCO_3)_2$)	12.6
Calcium bicarbonate ($Ca(HCO_3)_2$)	46.1
Ferric oxide (Fe_2O_3) and alumina (Al_2O_3)	.6
Calcium silicate ($CaSiO_3$)	7.3
Silica (SiO_2)	20.3
	113.8988

The second analysis by the Bureau of Chemistry was made at a later date and has not been previously published. The various constituents are as follows:

Analysis of Poland Spring water.

[W. W. Skinner, analyst.]

Gases (cubic centimeters per 1,000 grams at 0° C. and 760 mm. pressure):	
Carbon dioxide (CO_2), free	2.10
Carbon dioxide (CO_2), set free from bicarbonates on evaporating to dryness	10.20
	Parts per million.
Phosphoric acid radicle (PO_4)	Traces.
Metaboric acid radicle (BO_2)	None.
Arsenic acid radicle (AsO_4)	None.
Silica (SiO_2)	15.40
Sulphuric acid radicle (SO_4)	3.29
Bicarbonic acid radicle (HCO_3)	55.63
Nitric acid radicle (NO_3)	3.98
Nitrous acid radicle (NO_2)	None.
Chlorine (Cl)	5.90
Bromine (Br)	None.
Iodine (I)	None.
Iron (Fe) and aluminum (Al)	.32
Manganese (Mn)	None.
Calcium (Ca)	14.37
Magnesium (Mg)	2.38
Potassium (K)	.90
Sodium (Na)	6.34
Lithium (Li)	None.
Ammonium (NH_4)	.011
Oxygen to form Fe_2O_3 and Al_2O_3	.130
	108.651
Free ammonia	.01
Albuminoid ammonia	.005
Nitrogen as nitrates	.900
Nitrogen as nitrites	None.
Oxygen consumed	4.00

The volume of flow of the Poland Spring is reported to be about 8 gallons a minute. The temperature averages 42° and rarely varies 2° the year round. It is little affected by rain, and then only after the lapse of considerable time. The spring water is used for drinking at the Poland Spring House and the Mansion House near by and is bottled and shipped.

The Poland Spring is said to have been accidentally discovered in 1845. The hotel was built in 1876. In 1906 a fine plant, consisting of a spring house and bottling works, was installed at a cost of more than $100,000. In the vicinity of the Poland Spring are situated a

number of other springs from which some water has been sold. One of these waters, sold near by, went for a while by the name of "Poliska water." Some years ago a well was sunk on the west side of the hill in an attempt to tap the Poland Spring, but without success.

Cliff Spring.—The Cliff Spring is situated one-fourth mile west of East Turner, and the water is sold in Lewiston. The flow is reported to be 1½ gallons a minute.

Windsor Mineral Spring.—The Windsor Mineral Spring, owned by the Windsor Mineral Spring Company, of Boston, is situated 3 miles northeast of Lewiston post-office, on the slope of a rock hill which rises 100 feet or more behind the spring. The surface deposits consist of several feet of bowlder clay. The water is said by the owners to issue from rock. The formation is pegmatite, gneiss, and schist. The slope of the hill is grassed over and covered in part by an orchard. The only buildings in the vicinity are a house and barn, situated 500 feet horizontally along the hillside, thus giving no opportunity for pollution by drainage. The flow is reported to be 5 or 10 gallons a minute and to be invariable. The temperature is said to vary 2° or 3°.

The water is sold in Boston, New York, and other cities for table and medicinal purposes. Some of it is carbonated. The charge for still water is $1.50 a 5-gallon carboy. The spring is well protected by a cement curbing and is covered by a small spring house.

This water contains 154 parts per million of total solids. The complete analysis, recomputed according to the standard system, from the analysis reported in the company's circular, is given in the table (No. 208).

Lake Auburn Mineral Spring.—An important spring is situated on the northwest shore of Lake Auburn, at the foot of a gentle bowlder clay and gravel slope, near the lake. Formerly the site of this spring was used for a summer resort and there was a large hotel here, but a few years ago the hotel was destroyed by fire and it has not been rebuilt. The spring is still covered with a small spring house, and many people from the village of North Auburn come here for drinking water.

PUBLIC SUPPLIES.

Several communities in Androscoggin County—Lewiston, Auburn, Mechanic Falls, Livermore Falls, Lisbon Falls, and Lisbon Center—have public water supplies. The last two mentioned are, however, the only ones using underground sources.

The village of Lisbon Center has a public supply owned by Mr. Herbert G. Spear, the water being derived from springs. The supply is distributed from a tank through galvanized-iron pipe, and the water is called good. The amount used per day is reported to be

1,500 gallons. The pressure is 15 pounds. The water mains are about 1 mile in length, and there are 30 taps. There is no fire service.

Lisbon Falls obtains its supply by direct pressure from two springs owned by the Sylvester Aqueduct Company.

CUMBERLAND COUNTY.

GENERAL DESCRIPTION.

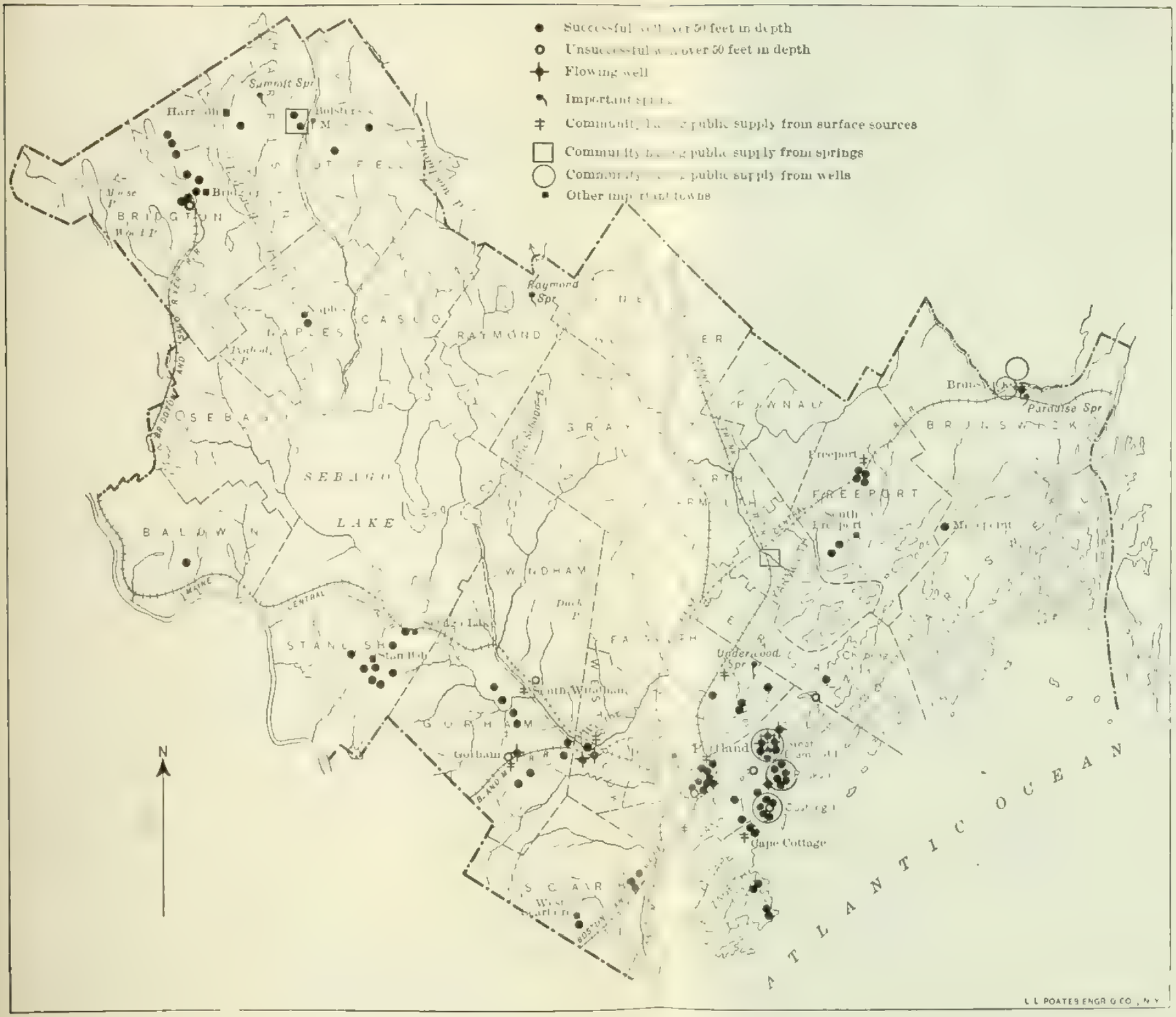
Cumberland County lies in the southwestern part of the State, bordering on Casco Bay and extending inland toward the New Hampshire line. It has a length north and south of about 45 miles and a breadth east and west of about the same distance, and covers a total area of 1,014 square miles. The population according to the census of 1900 was 100,689. This county contains Portland, the largest city of Maine, which in 1900 had a population of 55,167. The county includes many large lakes, especially in the western part, the largest being Sebago and Long lakes and Thompson Pond. It contains nearly the whole of the Presumpscot River system, Saco River follows the western edge for 16 miles, and Androscoggin River near its mouth borders the eastern corner for a similar distance. The county is relatively hilly, ranging in altitude from sea level to more than 1,300 feet above sea level in the northwestern part. Along the coast are scores of islands, large and small, which are utilized extensively as summer resorts. A map of Cumberland County, showing the distribution of deep wells, important springs, and communities having public supplies, forms Pl. XII.

In the interior districts of Cumberland County the prevailing type of well is the old-fashioned dug well, but in the vicinity of Portland and on the various islands of Casco Bay drilled wells are abundant and are generally successful. The range in depth is from 30 feet to more than 800 feet, the most common depth being between 50 and 100 feet. A few drilled wells in the vicinity of Portland and a number of driven wells on the flood plain of Androscoggin River near Brunswick overflow.

UNDERGROUND WATERS.

RELATION TO ROCKS AND SURFACE DEPOSITS.

Character and distribution of rock types.—As in Androscoggin County, the prevailing type of rock is granite. Only the region in the southern part of the county, lying between Sebago Lake and the sea, and small areas along the coast and on the islands, consist of slate and schist. These areas include Portland, Cape Elizabeth, Scarboro, South Portland, Gorham, parts of Windham, Westbrook, Deering, Freeport, and the island portions of Cumberland and Yarmouth. In the extreme northeastern part of the county, in much of Harpswell and in the eastern half of Brunswick, is an area of "complex" in which



MAP OF CUMBERLAND COUNTY.

Showing distribution of deep wells, important springs, and communities having public supplies

granites and gneisses alternate with slates, schists, and other rocks. which can not be subdivided in mapping.

Along the coast between Cape Elizabeth and Brunswick the rock varies in nature from hard, gneissic, and locally almost granitic rock to a very soft and schistose formation. The prevailing strike is northeastward, and this peculiarity accounts for the northeast-southwest elongation of the islands in Casco Bay. In general, the stratification and cleavage coincide rather closely in strike, although they may vary considerably in dip. Here and there the strata are much contorted, but the cleavage is generally rather uniform and for the most part nearly vertical, although in places it is considerably inclined. On Peaks Island the strike averages N. 40° to 60° E., and the dip ranges from 30° to 60° NW. The cleavage there is parallel to the dip. In many places the cleavage planes are open and would seem to allow opportunity for considerable water to penetrate downward into the rocks.

The mainland of Portland and parts of Deering and Westbrook differ considerably from the coast and islands, being composed of nearly pure slate which shows little trace of schistosity. This is the general type of slate found farther inland in Maine. In Portland and vicinity the slates are cut by intruded trap and granite dikes. At many places near its borders the granite contains masses of slate, and, like the slate, it is cut by dikes of trap. This indicates that the slate was the first rock formed, that is was intruded by great masses of molten granite, and that later both slate and granite were intruded by small masses of basic rock in the form of dikes which may now be seen cutting those rocks.

The joint cracks in the vicinity of Portland correspond in trend to those developed in other parts of the State. On the other harbor islands the main joints trend approximately N. 30° E., and N. 70° W. At Woodfords they are irregular. Some are nearly vertical, and the most persistent hade is toward the northwest, but a few vertical joints run in an east-west direction. One of the best exposures of this slate can be seen in a large ledge at Fish Point, in the Grand Trunk Railway yards at Portland.

On the islands in Casco Bay the cleavage is inclined at a high angle with the stratification, the latter being much contorted. In places the cleavage and stratification correspond, but such agreement is generally accidental. The strike of the cleavage is N. 40° E., and the hade is from 30° to 90° NW. In places the rock is very shaly. The joint cracks at these places are very irregular, but one system runs between N. 20° W. and N. 50° W. These joints are rather numerous, but not persistent. The rock contains a great many quartz veins.

The structure of the slate and its adaptability for holding water are shown by phenomena recorded in the drilling of wells at Portland.

In one well the drill dropped several inches when water was struck at a depth of 288 feet.

Surface deposits.—The surface deposits of Cumberland County are very diversified in nature. In the towns bordering the coast there are large areas covered by clay, which in many places is in turn overlain by flat sand deposits. The upper surface of the clay is not flat but undulating, so that the overlying sand is not everywhere of the same thickness. Along the coast the clay does not in general rise more than 60 feet above tide, but in the valleys of Presumpscot and other rivers it is in places as high as 150 feet. The clay and sand plains are several square miles in extent. The clay is also underlain in many places by sand and gravel in which water may generally be found. A typical section showing the relations of the clay to the other deposits is exposed at Portland.

Typical section of drift at Portland.

	Feet.
Dark-brown clay with a few bowlders	10
Fine stratified sand	8
	18

Another type of section is as follows:

Section of drift near Westbrook.

	Feet.
Coarse heterogeneous gravel	5
Stratified dark-brown clay	6
Fine horizontally-stratified sand	3
Coarse semistratified gravel	5
	19

The following section is exposed in a cut in Munjoy Hill on Washington street, Portland:

Section on Munjoy Hill, Portland.

	Feet.
1. Coarse gravel	3
2. Stratified gravel	10
3. Stratified, contorted, and eroded clay	5
4. Hard blue bowlder clay	10+
	28+

On top of No. 3 in this section a large amount of water can be seen seeping out of the hill. On the east side of the hill there are great gullies from which springs issue, apparently on top of the same bed. As a reservoir is situated on the summit, it is possible that the water has its source in leakage.

A few exposures in the city of Portland show that the upper part of both hills on which the city is built consists of gravel, while rock forms the core at depths of 100 feet or so below the summit. Considerable areas in Portland outside the peninsula consist of clay rising to a maximum height of 100 feet above tide. Generally these clays

are underlain by sand or gravel which may contain water. In some of the brickyards considerable water seeps out of the clay near its base. The top of Bramhall Hill is reported to have once been a swamp, and the water which seeps out around both sides of the hill probably comes from this source. Springs are reported to have once been abundant on this hill.

Away from the coast the drift is thinner. On the highlands it is generally of the ordinary type of bowlder clay, from 1 to 10 feet or more thick. About Sebago Lake, however, and in some of the broader valleys there are flat sand deposits of considerable thickness. Some undulating sand and gravel deposits are found on the highlands.

Buried valleys.—In most places the stratified drift deposits are underlain by rock at no considerable depth. Elsewhere, however, along ancient buried river valleys, the clay is of great thickness. Such a structure is found underneath Fore River between Portland and South Portland, where borings made during the construction of Vaughan's bridge showed the bed rock descending with a fairly regular drop from sea level at Portland to 110 feet below tide on the South Portland shore. A short distance south of this place the rock reaches the surface again and outcrops near Cape Elizabeth depot. In the construction of Vaughan's bridge two rows of 13 borings each were put down as tests. A sample record of the strata passed through is as follows:

Record of boring at Vaughan's bridge, Fore River, Portland.

	Feet.
1. Water	11.9
2. Soft black silt	21.4
3. Soft silty sand and peat	21.0
4. Very soft blue clay with silt	52.8
5. Coarse gravel and sand, hard	2.4
6. Slate.	
	109.5

No. 3 is nearly pure peat in some borings; in others it is made up largely of sand. It is reported in only 10 out of the 26 borings, and when mixed with sand has a thickness of 5 to 30 feet, rising within 33 feet of mean low water. No. 4 is typical blue clay, and its surface rises from 55 feet below tide at South Portland to low-water level at Portland. No. 5 is a stony bowlder clay.

The two kinds of buried valleys, those in the clay surface and those in the underlying bed rock, indicate that Fore River was the outlet for a stream of some size both before and after the deposition of the clay. It is probable that rock valleys of this kind extend many miles inland at several points along the coast, although they can not be traced on the surface owing to the great thickness of glacial drift. It may be expected that water supplies will be found by drilling wells in these filled valleys at some distance back from the coast.

WELLS.

GENERAL DESCRIPTION.

Types of wells used.—In Cumberland County, as nearly everywhere else in Maine, open wells are by far the most abundant type. The most common depth is probably 25 feet, and the wells are usually dug in bowlder clay or gravel. As a rule they are fairly successful, but the quality, volume, head, and persistence of the water vary greatly. A few wells, such as some of those driven on the flood plain of Androscoggin River for the towns of Brunswick and Topsham, obtain flows of water from a depth of 25 to 35 feet. This is possible only in a few favored localities. In some localities wells driven through soft clay into the underlying sands and gravels obtain water of good quality. Drilled wells are generally successful.

Drilled wells.—In Cumberland County there are no deep wells sunk exclusively in drift; however, the borings for Vaughan's bridge in Portland go to a depth of 110 feet below tide before striking rock. This suggests the possibility of getting water along similar buried valleys. It may be worth while to mention the case of the Merrimac Valley in Massachusetts, where a number of wells were drilled into the gravels underlying the clays at considerable depths and a few flowing wells were obtained. Although there is no certainty that similar wells could be obtained in Maine, it is probable that wells sunk at any point along the old valleys would obtain plenty of water.

In Cumberland County the number of drilled wells which have been sunk is somewhat over 120. The diameter of these wells varies from 4 to 8 inches according to the situation and the quantity of water desired, but the common diameter is 6 inches. The depth ranges from 40 feet in a few wells to 830 feet in an unsuccessful well drilled at the Maine General Hospital.

Quantity of water.—The most common depth of well is 50 to 100 feet, and the depth to the principal vein of water is generally within the same limits. Some wells, however, find the principal water vein as deep as 200 feet. The wells are most closely grouped at Portland and on some of the islands in Casco Bay and in the town of Standish. Most of them are successful, although in a few no water was obtained, and a few wells are reported along the coast in which the only result was salt water which had probably penetrated inward from the sea. The quantity of water found varies greatly, from less than a gallon to 60 gallons a minute. The common capacity is not more than 10 gallons a minute. The best wells known in the county are at Portland. Generally the wells are permanent, but it has been necessary to drill a few of them deeper, and some have been abandoned because of decrease in supply.

Quality of water.—As elsewhere in Maine, the quality of the water is dependent largely on the kind of rock in which the well is drilled. It is found that the lowest amount of total solids is generally obtained from granite, although typical hard blue slate of the type found on the mainland at Portland generally gives water of moderate mineral content. Where the rocks are more schistose, however, and especially where they are mixed with trap and granite, approaching the type known as "complex," the water is of poorer quality, generally being higher in sulphates and carbonates and more commonly containing iron. There is probably no place in Cumberland County where the water is so highly charged with mineral matter as to be unsuitable for use in boilers, but sea water has penetrated and ruined a few wells. Generally the well waters of this county are low in mineral matter, and where kept safe from pollution by organic matter they are perfectly satisfactory for drinking. The table of analyses on pages 77–83 shows that the total solids in rock wells in this county run from 25 to more than 600 parts per million, with one higher report (2,008) due to sea water. The ordinary amount of total solids is from 100 to 150 parts, and the hardness from 16 to 176.

Uses.—Most of the wells in Cumberland County are used for domestic supplies. In Portland, however, they are used in several office buildings for both drinking and boilers and in a number of factories. On the islands of Casco Bay they are used to supply summer cottages. Several of these islands have installed public supplies from rock sources. Brunswick has a supply from deep wells in gravel and sand. Most of the wells of the county are pumped by hand or by windmill, but those used for public supply and some private wells are pumped by power. Several of the forts in Casco Bay are supplied by wells.

Flowing wells.—In Cumberland County 10 flowing wells are reported, exclusive of the wells of the Brunswick and Topsham water district, which flow at times. Most of these are situated on the islands of Casco Bay, but one of them is in Gorham and one in Westbrook. The greatest head is about 3 feet above the surface, and the greatest yield is about 2 gallons a minute. With few exceptions the water is suitable for any use.

DETAILED DESCRIPTIONS.

City of Portland.—The drinking-water problem is not pressing in the city of Portland, for the reason that an excellent supply is obtained from Sebago Lake, a body of water so large that it is little affected by any polluting influence. However, the number of summer cottages and hotels situated on the lake and its tributaries is increasing rapidly, and several steamboat lines are run regularly on the lake. It is feared, therefore, that the water may in time become dangerous if no precautions are taken to stop the increase of contaminating

influences. (See p. 125.) But at present the water supply of the mainland portions of the city is excellent, and the advantage of wells lies principally in a saving of water bills. Several companies and individuals have drilled deep wells for that reason, and on the islands of the harbor a number have been sunk for supplying summer cottages. In all, more than 30 drilled wells have been sunk within the city limits.

The deepest well known to have been drilled in the State of Maine was sunk in 1902 at the Maine General Hospital, on Western Promenade, overlooking the union station. This well was sunk to a depth of 830 feet. It was drilled by an experienced driller, who contracted to supply 16 gallons of water a minute, the price of the well being $2,000. Only 3 gallons a minute were obtained, and this was not sufficient for the hospital needs. The driller requested permission to "shoot" the well with 200 pounds of dynamite, but his request was refused and the well was abandoned.

This well was situated 150 feet distant from a successful well 505 feet in depth at the same hospital, which obtained 13 gallons of water a minute and cost $3,290, including the engine and pump. This well was sunk in 1902 to a depth of 100 feet. A year later it was deepened to 505 feet, its present depth. The first 24 feet of this well is through gravel, the next 76 feet through clay, and the rest through slate. It yields more than 21,000 gallons of water a day, and the water is of very good quality. The analysis (No. 45) shows 177 parts per million of dissolved solids. The sanitary analysis showed the water to be perfectly safe.

In the well drilled for Mr. D. F. Emory the following strata were encountered:

Record of D. F. Emory well, Portland.

	Feet.
Fine sand	12
Gravel and sand	30
Hard "sandstone"	10
Rock	76
	128

In a 298½-foot well belonging to Burgess, Forbes & Co. the strata were as follows:

Section of Burgess, Forbes & Co. well, Portland.

	Feet.
Gravel	14
Clay	65
Clay and gravel	18
Clay	52
Slate	61
"Granite"	88½
	298½

If the "granite" is really granite, it indicates the extreme irregularity in distribution of this rock beneath Cumberland County.

One of the best wells in the city is that belonging to Mrs. Mary J. Frazer, at the corner of Franklin and Fore streets. This is a flowing well 210 feet deep, in slate. It is pumped by a windmill and is reported to yield 25 gallons of water a minute and to supply drinking water for a large number of tenements in the vicinity. Water was obtained at a number of different depths, but the best vein was tapped at the bottom of the well. The owner reports the use of this well as a great saving in expense over city water. It is a fine, clear water, and contains 25 parts per million of total solids, a lower amount than exists in the water of any other deep well in the city. An interesting feature regarding this well is that although it is situated but a few hundred feet from the sea, where the normal amount of chlorine is over 6 parts per million, only 1.4 parts of chlorine were found in this water. This may mean that the water comes from a source some distance inland.

An unsuccessful well was drilled in 1887 for the Consolidated Electric Light Company of Maine, on Plum street. This well is 8 inches in diameter. Salt water was struck at 140 feet from the surface, and the well was drilled to 204 feet in the hope of getting water of better quality. It yielded 65 gallons a minute, and the well could not be pumped dry, but the water was too salty for use. The well was then plugged at a depth of 145 feet. An analysis was made, and the result showed the total solids to amount to 2,008 parts per million, of which 1,912 were readily soluble and 96 insoluble by heating. The water was rather alkaline and contained a trace of iron. The analyses showed that there was less calcium carbonate than before plugging and that nearly all the magnesium carbonate was shut off; the sodium chloride increased considerably. The water has great tendency to scale and corrode the boilers. As the total solids in this water do not approach the amount in sea water, it can not be pure ocean water, but is considerably diluted with rock water.

Another unusual well is the one belonging to Mr. James P. Baxter, at Baxter Block. Mr. Baxter reports his well water to be better than Sebago water, because the latter will show a slight sediment on standing, whereas that from his well will not. This well nearly flows. It is said that when the drilling had reached a depth of 76 feet no water had been found, but at that depth the drill suddenly dropped for a distance of more than 80 feet through a cavernous space. If this report is accurate, it is probable that a vertical joint crack of considerable size was encountered.

The well drilled for E. T. Burrowes & Co. is 106 feet deep and becomes a flowing well in the spring. Analysis of this water showed pollution by sewage, and it is not used for drinking.

On account of the general use of Sebago water in Portland there are few dug wells within the city limits. The former town of Deering now belongs to Portland and has for years used the city supply. There are a few dug wells in the vicinity of Woodfords, but these are not used for drinking water, as the population has become too dense to make water from shallow wells safe. In quality the Portland water is very good, as regards both purity from pollution and low mineral content. The analyses of waters from 11 deep wells in the city are given in the table (Nos. 37 to 47).

Peaks Island, Portland.—The shore of Peaks Island consists almost entirely of bare rock and bowlder clay, but the interior, rising at points to a height of more than 80 feet above tide, is covered in places by sand and clay which are locally 20 feet or more in thickness. The rock consists of slate and sandy schist striking northeast and having a nearly vertical dip. In hardness the rock varies greatly, as it is cut by a great many small veins of quartz.

There are many open wells on the island, the most common depth of which is 15 feet, and these generally afford plenty of water. The capacity of some of them has been increased by blasting a few feet in ledge. On account of the increasing summer population of the island surface wells are no longer safe. Wherever practicable their use should be discontinued and deep wells or the public supply be substituted.

Drilling on the island is comparatively easy, and a number of deep wells have been sunk. Their depth ranges from 45 to more than 200 feet. The best wells on the island are the two drilled for the Peaks Island Water and Light Company, which are 202 feet deep. These wells are connected by a natural fissure below the surface and together will yield 85 gallons a minute with the pumps running twenty-four hours a day.

On Peaks Island there is one flowing well, belonging to Mr. C. W. T. Goding, of the Casco Bay Steamship Company. The mouth is only a few feet above tide. This is an 8-inch well, 135 feet deep. By pumping, it yields 52 gallons of water a minute. No failures are known on the island, but two or more wells obtain only 2 or 3 gallons a minute each. A few people have used springs, but these are now abandoned. Two analyses of deep-well waters on this island are given in the table (Nos. 35 and 36).

Great Diamond Island, Portland.—The surface of Great Diamond Island is mostly bowlder clay, with slaty ledge outcropping in a few places. The west side of the island is low; the east side is high and rocky. The rock is similar to that on Peaks Island, but is more slate than schist. Many wells here, even including two of those belonging to the water company, are only open wells a few feet in depth, some of them blasted 2 or 3 feet into the ledge. Two wells drilled

on the western shore for the Diamond Island Association were successful; they yield 12 and 15 gallons a minute and now supply about 60 buildings, mostly cottages. The water is found at a depth of about 100 feet in gneiss. Analysis No. 31 gives the composition of water in one of these wells, and No. 32 is a field assay from the other.

At Fort McKinley, on the north end of Great Diamond Island, seven wells have been drilled at various times for the United States Government. They range from 95 to 302 feet in depth, and water is found at depths of 80 to 100 feet. Two or more of them were abandoned because of insufficient supplies, but the rest yield a maximum amount of 4 to 40 gallons a minute. The detailed description of these wells may be of benefit in future deep drilling on neighboring islands.

Well No. 1, 97½ feet deep, overflowed the surface before pumping. The test showed 25 gallons a minute. Well No. 2, 95 feet deep, situated 150 feet east of No. 1, taps the same vein, and before pumping the water overflowed the surface. In the test it showed 30 gallons a minute by pumping, and when pumped with No. 1 it will supply 48 gallons a minute. Well No. 3, situated 150 feet south of No. 1, is 265 feet deep. The test showed 15 gallons a minute. Well No. 4, situated 300 feet northwest of No. 1, is 302 feet deep and supplied 14 gallons a minute in the test. In wells Nos. 3 and 4 the water stands at 15 to 20 feet below the surface. The pumps are down 125 feet and 150 feet, respectively. In these wells 15 to 18 feet of drift was penetrated on top of the rock; the remainder is schist, much of which contains pyrites. The total capacity of all four wells during the wet season of 1902 and 1903 was 84 gallons a minute. The total capacity during the dry season of 1904 and 1905 was 30 gallons a minute. In dry seasons wells Nos. 1 and 2 can be exhausted.

Little Diamond Island, Portland.—Little Diamond Island is situated just south of Great Diamond and is connected with it at low tide by a sand bar. So far as the structure of the rocks is concerned, it is but a continuation of Great Diamond Island. On Little Diamond one well has been drilled to a depth of 170 feet and obtains 4 gallons a minute from 160 feet below the surface. Most of the wells on this island are dug wells less than 20 feet in depth. These are perfectly safe if situated on the uphill side of all houses. At the east end of Little Diamond Island is a light-house at which the Government has a well 171 feet deep. The water in this well is salty and contains total solids amounting to 460 parts per million, the chlorine being 397 parts, carbonates 80 parts, and sulphates also high. The unusual composition is due probably to a considerable admixture of sea water.

House Island, Portland.—House Island consists of solid rock round the sides, but there is some drift on top. On this island a single well was sunk to a depth of 170 feet. It is reported to supply 15 gallons a minute.

Cushing Island, Portland.—Cushing Island is the most southerly of the group of islands in Portland Harbor, and is about a mile in length. The cover, of till, is 1 to 5 feet or more in thickness, and the underlying rock is schistose gneiss of varying degrees of hardness. This island is a better collector of water than some of the others, because it has a few depressions in the surface and less bare rock. The principal system of joint cracks here strikes N. 40° to 50° W. and hades N. 25° from the vertical, the joints being from 3 to 10 feet apart. A second system strikes N. 80° W. to N. 70° E. and hades N. 10°. The third system, probably sheet joints, strikes north and south and dips toward the west at 20° to 30° from the horizontal. Along the shore a great many irregular joints can be seen.

On this island there are several private wells which strike water at depths of 80 to 275 feet, and the United States Government has drilled four or more wells at Fort Levett. There are a few dug wells on the island, but most of the residents use water from a drilled well belonging to Mr. Cushing.

The most extensive drilling on the island was for Fort Levett. Here several wells have been sunk and abandoned. Official records have been kept of only the three most recent ones. Well No. 1 struck rock at 18 feet and was cased to 28 feet. Its total depth is 277.2 feet. A forty-eight hour test on January 4, 1906, showed 30 gallons of water a minute. The rock resembles hard mica schist or quartzite. The pump barrel is down 150 feet. When pumped the water falls below this level. Well No. 2, drilled in 1906, is 326 feet deep. It penetrates 11 feet of soil and clay and is cased to a depth of 74 feet. The water level before pumping stands within 20 feet of the surface, but while pumped it stands 300 feet lower. On the test this well supplied 10 gallons of water a minute, but this was not considered enough, and a new well was drilled. Such a well should not be abandoned, as 10 gallons a minute is a good yield in Maine. Well No. 3 struck rock at 15 feet and is cased to 27 feet. The water stands 20 feet below the surface. On January 3, 1907, it was 176 feet deep, but no report has been obtained since it was completed.

Long Island, Portland.—The rock on Long Island is mostly schist, which splits easily along the bedding planes, standing nearly vertical The island contains a great many cottages, but no public supply is used. The only wells are of the old-fashioned open type.

Cow Island, Portland.—A flowing well is reported to have been drilled at Fort Lyon, on Cow Island, in 1906. The natural flow was 6

gallons a minute, and the capacity by pumping is reported to be 40 gallons a minute.

Gorham.—A number of drilled wells have been sunk in the town of Gorham, and so far as known they have been successful, as regards both quality and quantity of water. The deepest well is that of Mr. J. H. Rines, in the eastern corner of the town. This well was drilled all the way in solid rock. The drilled wells are about a dozen in number, and range in depth from 40 to 307 feet, generally supplying enough water for domestic purposes from a formation which is mostly slate. In the eastern part of the town the dug wells average 15 feet in depth and contain, as a rule, 5 or 6 feet of water in the dry spell, though some of them dry up. One dug well is more than 60 feet deep, in till, and for fifty years has never been known to be dry. The analysis of water from a 66-foot rock well is given in the table (No. 30).

Westbrook.—The formation at Westbrook is for the most part slate, but the northern part of the town is underlain by granite. The bed rock is only a few feet below the surface. In that section the wells are open wells, only 10 to 20 feet in depth. Many wells go dry during the summer, but those blasted a few feet in ledge give plenty of water.

In the vicinity of Saccarappa there are two flowing wells, one owned by Mr. Rufus Jordan, the other by the Haskell Silk Company. These wells are both 216 feet in depth and obtain their flows near the bottom of the well. The surface rock is slate, but one or both wells are reported to enter granite. It is possible that the flow may be caused by the penetration of water downward from the hills along the contact between the granite and the slate, but this conclusion has not been definitely proved. The composition of the water in the flowing wells is given in the table (Nos. 51 and 53).

Chebeague Island, Cumberland.—Chebeague Island is the largest of the islands in Casco Bay, being more than 3 miles in length. Like other islands of the bay, it consists mostly of schist, but the surface of the interior is made up in part of sand. It is easy to get water from shallow wells, and for that reason only one drilled well has been sunk on the island. The depths of the dug wells are only 6 to 20 feet. The water is mostly safe for drinking. The abundance of water on this island is due to the thickness of the drift covering and to a swampy depression which lies on the high land of the interior. The only drilled well is owned by Mr. E. A. Ballard. This well was drilled to a depth of 52 feet and obtained plenty of water. Later it was sunk to 80 feet, and still later to 301 feet. The latter extension was unsuccessful, not increasing the supply. The water is good and clear, and the supply has increased in volume through natural causes since the well was drilled. The amount is small, but is sufficient for domestic purposes at the cottage.

Little Chebeague Island, Cumberland.—Little Chebeague Island bears the same relation to Chebeague Island that Little Diamond Island bears to Great Diamond. Little Chebeague is connected with the main island at low water by a sand bar. All over the island the drift is thick, 40 feet or more of it being exposed in a nearly vertical cliff on the north side. On top of this bluff, not many feet from the edge, a well was drilled to a depth of 197 feet. Rock was struck at about 100 feet. The water is good and was at first plentiful, but the supply has diminished until now there is not enough to supply one family. Another well should be drilled to the east of this, and it is believed that there is an even chance of obtaining a better well. On this island a dozen or more cottages use open wells.

Windham.—The town of Windham is rather hilly, and the rock consists mostly of slate and schist. The wells are nearly all open wells, 10 to 40 feet in depth, but at South Windham two drilled wells have been sunk. One of these was a failure owing to improper casing; the other well supplies plenty of water for three or four families. Most of the people in the village use Sebago Lake water, as the Portland aqueduct runs near the village. A few springs emerging from gravel have been used in the vicinity, and the mills obtain water from this source. There is plenty of water in the gravel, and its quality seems to be very good. Some of the dug wells run dry during the summer.

Scarboro.—The greater part of the town of Scarboro consists of broad sand and clay plains rising from sea level to 100 feet or more above tide. On these plains the water level is only a few feet below the surface and excellent soft water can generally be obtained by driven wells, at a cost of only $12 to $15. The size of pipe commonly used is 1¼ inches.

In this town drilled wells are generally unnecessary, but on the hills and in some localities where the rock approaches the surface it is necessary to drill. On the road running from West Scarboro to Portland several wells have been drilled, which range in depth from 50 to 200 feet. They generally yield plenty of water for a house and farm. One of them, on the H. J. Libbey estate, gave 3½ gallons a minute for three and one-half hours in the test. In this part of town there are a number of dug wells 15 to 20 feet in depth. The formation on the hills and underneath the drift is slate.

In West Scarboro the deep wells are good, but most of them are less than 50 feet in depth. A number of springs in the vicinity are used to supply houses in the village. Some wells are bored in clay, and a few of these have been unsuccessful. Most wells here, however, supply enough water for a family from a depth of 30 to 35 feet. The best water is obtained by penetrating the clay.

At Pine Point Beach the wells are only 10 to 15 feet deep, driven in sand. On Blue Point Hill the wells are all dug, and some of them fail in summer. On Prouts Neck the formation is all rock. Conditions there have not been investigated, but it is probable that water can be obtained by deep drilling.

Cape Elizabeth.—The coast of Cape Elizabeth is very high and rocky and is greatly appreciated as a summer resort. The few wells that have been drilled along the coast range in depth from 60 to 120 feet, supplying summer cottages. The Shore Acres Land Company, however, has a well 151½ feet deep, which supplies a number of houses with good water. Away from the coast the wells are mostly shallow and are driven or dug in sand and gravel. In quality the rock water is generally good. An analysis of water from a 115-foot well at Cape Cottage reports 140 parts per million of total solids. The calcium here is 43 parts per million, which is high for southwestern Maine.

South Portland.—The coast of South Portland is mostly bold and rocky, like that of Cape Elizabeth. The surface varies from rocky hills to plains of clay overlain by sand. Nearly the whole town uses Portland water, and there is little demand felt for drilled wells. Several shallow wells on the clay plain penetrate the underlying gravel and obtain water of good quality. No drilled wells are reported. An interesting set of borings made for Vaughans Bridge is described under Portland (p. 107).

Falmouth.—The surface of Falmouth is made up of clay and sand plains rising to an altitude of 100 feet, broken by low hills of schist and granite. Throughout the town the wells are shallow and the conditions are variable. Part of the town is now using Sebago Lake water. In the southern part a number of drilled wells have been sunk, some of them more than 100 feet, and the chances for water have been found to be fairly good.

At Falmouth Foreside the Underwood Mineral Spring is situated.

Clapboard Island, Falmouth.—On Clapboard Island a single well has been drilled by Mr. S. F. Houston. It reached a depth of 210 feet. No information regarding this well has been received.

Standish.—In the town of Standish much drilling has been done, 18 wells having been put down by a single driller. The wells range in depth from 40 to 90 feet. The drilled wells are mostly open wells which have been deepened because of previous insufficient supply. The volume of water is still small, but is sufficient for all farm purposes, in some wells amounting to 10 gallons a minute. Some of these wells can not be pumped dry, but most of them are exhausted in a short time.

The well of Mr. Frank H. Rand was originally a 30-foot open well, blasted 22 feet in ledge. There was little water, and the owner

drilled to a depth of 60 feet, striking a pocket of water, which soon gave out. The well was afterwards deepened to 79 feet and obtained 10 gallons a minute. Most of the wells have been drilled in rock, but several near the village of Sebago Lake penetrate nearly 40 feet of sand. As a rule the water comes from crevices in a schistose rock. One shallow drilled well in Standish contained so much iron that it was not used. The only evidence of the composition of water in this town is derived from a field assay (No. 50).

Bridgton.—The town of Bridgton is believed to be entirely underlain by granite. In the village and town much drilling has been done at various times, 14 wells having been sunk by one driller. The depths range from 40 to 290 feet. So far as known, the wells of moderate depth have been successful, and a 200-foot well seems also to have been satisfactory. A well 290 feet in depth, however, was drilled for the Bridgton Aqueduct Company and yielded very little water. This is one of many examples showing the uselessness of sinking wells below 200 feet or so in granite. At North Bridgton and elsewhere wells are dug and seem to be mostly satisfactory. Several field assays (Nos. 3, 4, 6, and 7) of water from Bridgton wells have been made, but only one complete analysis (No. 5).

Harrison.—Several wells have been drilled at various times in the town of Harrison, one of them, high on a hill, being 90 feet deep and successful. Other wells—as several at Bolsters Mills—were only about 40 feet deep and obtained water, but were abandoned in favor of a spring supply which is now used by that village. On the hills many people use excellent springs which issue from bowlder clay and are pumped by windmills to houses higher up.

Otisfield.—Several drilled wells have been sunk in Otisfield, and the conditions seem to be favorable for obtaining underground-water supplies, but no data are at hand.

Brunswick.—Brunswick is an example of a city with a good water supply, taken from driven wells on the flood plain of Androscoggin River, as explained under the heading "Public supplies." Formerly the river water was used and typhoid fever was epidemic; later the water was purchased from Bath. So far as safety is concerned private wells are now unnecessary. In case individuals or companies desire to sink wells, they will probably succeed in getting sufficient water, either from shallow wells sunk through the surface sands and clays into underlying gravel or by drilling into rock. The former source is recommended for manufacturing establishments in situations where the surface deposits are of sufficient thickness.

Harpswell.—This part of the Maine coast is so uniformly rocky, and it is so difficult to get water from dug wells, that many people at their summer cottages have resorted to the ancient custom of using cisterns and rain water. Few people in Harpswell use drilled wells.

At the extreme end of Mere Point is one well 67 feet deep, in schist, which furnishes enough water for all the families—a dozen or more—having cottages on the end of the point. An analysis of the water from this well is given in the table (No. 33).

Freeport.—The public supply of Freeport village comes from Frost Gulley Brook. In the town a number of wells have been drilled to depths varying from 100 to 200 feet. They could not be pumped dry during a twenty-four-hour test and were used for some time, but were abandoned when the public supply was instituted. The well water is obtained in gneiss. Several wells at South Freeport, about 100 feet deep, obtain enough water for domestic uses from granite. Casco Castle at South Freeport obtains its supply from a spring situated 2 miles south of the hotel. Otherwise South Freeport uses shallow wells.

Other towns.—In the towns of Baldwin, Sebago, Naples, and New Gloucester some drilled wells have been sunk, but they are rare and scattered. In Casco, Raymond, Pownal, Gray, and North Yarmouth no drilling is known to have been done, and only open wells, with perhaps a few driven wells, are used.

SPRINGS.

General statement.—In Cumberland County springs are abundant. The topography is varied, the covering of drift is in many places thick, and springs seep out along the bowlder-clay hillsides. In the country districts water is pumped from some of these springs by windmills or hydraulic rams to houses on the hills above. Where springs are not situated within limits of pollution from neighboring houses the water is generally of good quality. One small village—Bolsters Mills—uses springs for a public supply. In many parts of the region covered by clay and sand plains it is common to find springs emerging from sand overlying clay. Some of these springs contain surprisingly small amounts of mineral matter and many are entirely free from organic matter.

The commercial mineral springs in Cumberland County which report sales are as follows:

Paradise Spring, Brunswick.
Pownal Spring, New Gloucester.
Raymond Spring, North Raymond.
Underwood Spring, Falmouth Foreside.

Paradise Spring.—Paradise Spring is situated in the eastern part of the town of Brunswick and is owned by D. D. Gilman & Bro., of Brunswick. It is renowned as having been a favorite resort of Nathaniel Hawthorne. The spring lies at the foot of a steep sand bluff, rising above the flood plain of Androscoggin River, not far from the waterworks of the Brunswick and Topsham water district. It is

supposed that the spring water percolates out of the sand above its contact with the clay, as seen in a number of roadside springs in the vicinity. The water is colorless, odorless, and tasteless. It has a temperature of 43° in winter and 45° in summer, and the stream coming out of the small pipe in the bank is reported by the owners to supply about 8 gallons a minute. This yield is said never to vary. The surroundings are wooded, and there are no buildings in the vicinity, so the spring is perfectly free from danger of pollution. The chemical composition is reported in analyses 217 and 218, recomputed from those reported in a circular issued by the owners. The total solids are only 18 parts per million.

Formerly Paradise Spring water was sold in Brunswick, but since the new city water system was installed there has been no demand for mineral water and the owners have gone out of the business. The price at which it was marketed was 75 cents a 5-gallon carboy. There is no spring house or other improvement at the spring.

Pownal Spring.—The so-called Pownal Spring is situated at New Gloucester, on rather high land, and there is believed to be no chance for pollution. The water is reported to flow from solid rock. Some years ago the Pownal Spring Hotel Company was incorporated and the water was analyzed with a view to establishing a hotel near the spring. The analysis, as recomputed from that reported in the company's circular, is given in the table (No. 221). The total solids amount to only 20 parts per million. The owners claim valuable medicinal properties for the water.

Raymond Spring.—Raymond Spring, situated at North Raymond, about one-eighth mile northwest of North Raymond post-office, was for twenty years prior to 1905 known as Wilson Spring. It is reported to issue from a fissure in granite about 100 feet below the summit of a hill. Formerly there was a hotel here, but some years ago it was burned. The flow is large and is said to diminish only slightly in dry seasons. The water is clear and sparkling, odorless, and tasteless. As there are no houses near by, it seems to be perfectly safe. It is used for drinking and medicinal purposes and is shipped and sold at 30 cents a gallon. The owners claim medicinal properties for it. An analysis of the water reported in a statement issued by the owners, recomputed into ions and parts per million, is given in the table (No. 222).

Underwood Mineral Spring.—Underwood Spring is situated at Falmouth Foreside, a few feet above sea level and only a short distance from the shore in a gully, the sides of which consist of clay. It is owned by the Underwood Mineral Spring Company, of Portland. The water is believed to issue from sand directly on top of the clay. The spring is bricked up, and the upper of its two openings is covered by a large glass pyramid. The water is colorless, odorless, and taste-

less. The flow is reported by the owners to be 140 gallons a minute, and the measured temperature is 46°. A large hotel is situated on the sand plain above the spring, several hundred yards distant from it. The locality is used as a resort, and the water is bottled and shipped for medicinal and table use. A 5-gallon carboy delivered on the train or in Portland sells for 75 cents. "Soft" drinks are also made. The bottling house is situated on the shore of the bay and the water flows directly from the spring to this place. The mineral analysis of the water, recalculated from the analysis of the water reported by the owners, is given in the table (No. 219).

Summit Spring.—Summit Spring is situated on very high land in the northern part of the town of Harrison. It is the site of a hotel, and formerly was extensively used. The yield is reported to be 38 gallons a minute and the temperature 46°. The analysis shows the total solids to amount to 68.9 parts per million.

PUBLIC SUPPLIES.

General statement.—The largest water supply in Cumberland County comes from Sebago Lake, whence it is carried by an aqueduct to the city of Portland. The surrounding towns also use this water where the Portland aqueduct lines are conveniently situated. Of the 15 communities in Cumberland County which have public water supplies 7 are supplied from surface sources, 4 from wells, and 4 from springs. Six of the communities having surface supplies use Sebago Lake water. These are Portland, South Portland, Cape Elizabeth, Westbrook, Gorham, and Falmouth Foreside. Freeport obtains its water from a brook.

The most important underground-water supply in the county is that of Brunswick, which has combined with Topsham, in Sagadahoc County, to install a supply obtained from driven wells on the flood plain of Androscoggin River. Peaks Island, Great Diamond Island, and Cushing Island, in Portland Harbor, have public supplies from drilled wells. The communities using spring supplies are Yarmouth, Yarmouthville, Bolsters Mills, and Casco. All these supplies are described in detail below.

Brunswick and Topsham.—Formerly the public supply of Brunswick was taken from Androscoggin River, and typhoid fever was prevalent in the village. That system was abandoned, and until recently water was purchased from the Woolwich Water Company, which supplies Woolwich and Bath from Lake Nequasset, in Woolwich. This supply was regarded as unsatisfactory; consequently, in 1904 a water district was established, embracing the towns of Brunswick and Topsham, with a population of about 7,300 persons to be served, and a new source of supply was sought in driven wells.

A test well, driven to hardpan on the flood plain of Androscoggin River 1¼ miles east of the Brunswick post-office, yielded an abundance of good water. Thereupon a number of other wells were driven in the same vicinity, 50 of which constitute the source from which the supply is taken. These wells are situated along a straight line extending a distance of about half a mile on the flood plain, not more than 10 feet above the river. Back of them rise several terraces, the highest of which is about 60 feet above the surface on which the wells are situated. At the base and along the sides of these terraces are many springs, the best known being the Paradise Spring, described on pages 119–120. The flood plain is composed of recent river deposits and is in places marshy. The upper terraces are composed of marine clays overlain by sand. The water seems to follow the upper surface of the clay beneath the sands and gravels, seeping out wherever the covering is thin or broken and saturating the sands and gravels to such an extent that they form practically an exhaustless reservoir. The facts that the water surface in the wells is considerably higher than the surface of the river and that its analysis is different from that of the river water show that the latter is not its source.

The wells are all of about the same character. They are 2½ inches in diameter, with a depth of 25 to 35 feet, depending on the height of the surface above the river. The principal water bed is very coarse sand from 5 to 10 feet thick, overlain by 15 to 20 feet of finer sand and 3 to 6 feet of sand and clay. Underlying the water bed is a considerable depth of "hardpan," consisting of clay and sand. A test well was driven 155 feet, when bed rock was apparently encountered, as it was impossible to drive farther. Under normal conditions the water in the wells rises within a foot of the surface, but in the spring and after heavy rains some of the wells flow, yielding about 5 gallons a minute. In order to estimate the capacity of the wells a test was undertaken, beginning September 21, 1904, and continuing night and day for thirty days. Nine wells were connected with a fire pump having a 10-inch cylinder and a 12-inch stroke. The result of the tests showed an average yield of 1,003,732 gallons daily. The total yield from the entire series of wells is estimated at about 5,000,000 gallons daily.

The water supplied by the wells is as soft and excellent in quality as any other public supply in Maine. Analyses, recomputed into ions and parts per million from those reported by the company, are given in the table (Nos. 177–179).

From the wells the water is pumped to a standpipe, 145 feet above the town, having a capacity of 650,000 gallons. The mains are 13¾ miles in length. There are 80 fire hydrants in Brunswick. The average pressure is 60 pounds. About 5,000 people are supplied with water.

Peaks Island, Portland.—A large part of Peaks Island is supplied by a water system owned by the Peaks Island Water and Light Company. The water is obtained from two drilled wells situated close together near the south end of the island, not far from the village. The wells are sunk in solid rock and are unusually satisfactory for drilled wells, as explained under the description of wells on Peaks Island (p. 112). They are pumped by two steam pumps. The test showed that 50 gallons a minute could be obtained from the older of the two wells, this being the full capacity of the pump. During the test the water surface was lowered 35 feet. The test of the newer well showed 110 gallons a minute for seven hours, when the water gave out. There is, however, a plentiful supply of water in the two wells, and they can be pumped together at the rate of 75 gallons a minute day and night. The water mains belonging to this company are about 7 miles in length. Two miles of these are "under frost," or buried deep enough so that they can be used during the winter. The other 5 miles are "above frost" and for the most part on the surface. The pipes used are 8, 6, and 4 inches in diameter. The owner, Mr. E. E. Rounds, reports that 255 takers are on his books. Most of these people are cottage holders, and they have unlimited use of the water at $10 a year. Seven hotels are on the system, and some of these pay as much as $100 a year. The water of the company has been analyzed, but the analysis has not been received by the Survey. From a sanitary standpoint the water is believed to be as pure as could be desired. The pressure on the main street is 60 pounds.

At the north end of Peaks Island there is a smaller system of waterworks, owned by the Beacon Hill Water Company, which has a drilled well 70 feet in depth pumped by a hot-air pump. More than 30 buildings are reported to be supplied by this system.

Great Diamond Island, Portland.—Great Diamond Island is largely supplied by a water system owned by the Diamond Island Association. The water is obtained from wells, 2 of them being ordinary dug wells and 3 others being drilled to a considerable depth in solid rock. The dug wells are little used, as the water has been found not very good. The drilled wells are pumped by hot-air engines and windmills. The supply is adequate for the island except sometimes in the summer season, when it is necessary to resort to private wells or to the surface wells owned by the company. It is supposed that about 60 cottages are supplied with water from these sources. The supply is satisfactory except that in summer the water becomes so warm, owing to the pipes being laid on the surface of the ground, that it is not used for drinking. In consequence of the position of the pipes the supply has to be discontinued during the winter. An analysis of water from one of the drilled wells is given in the table

(No. 31). Other data relative to the wells will be found on pages 112-113. From the wells the water is pumped to a tank situated on the hill in the center of the island, the capacity of the tank being 60,000 gallons and the pressure 30 pounds. A smaller tank is situated near by. There is no fire service. About 10,000 gallons a day are used.

Cushing Island, Portland.—A hotel, stable, and about a dozen cottages on Cushing Island are supplied by a 275-foot well owned by Mr. Francis Cushing. The water is pumped by a deep-well steam pump through 2½-inch pipe to three tanks on top of the hill. The well and pump are inclosed in a pump house, and the pump is operated eight to nine hours a day. At one time it was tested five days continuously without failure, and the yield was variously reported at 40 to 70 gallons a minute. The water is fine and clear and has a measured temperature of 52°.

Yarmouth and Yarmouthville.—These villages have a public water supply from springs belonging to the Forest Paper Company, but the system is owned by the town. The springs are reported to issue from sand at the base of a rocky hill at a rate of 100 gallons a minute. The water is distributed from a standpipe 100 feet in height and 50 feet in diameter, its capacity being 265,000 gallons. The pressure is 60 pounds. The water is good, and 130,000 gallons a day are used for farm and domestic purposes. There are 8 miles of mains, 800 taps, and 57 fire hydrants, and the system supplies 2,000 people. So far as known the supply is satisfactory. Royal River furnishes an emergency supply.

Bolsters Mills.—More than 20 families and the stores at Bolsters Mills are supplied by two springs situated just east of the village. The springs issue from bowlder clay a few rods distant from the base of a high gravel moraine. The springs proper are dug holes, 3 by 3 feet in size and 2 feet deep, with an outlet pipe and strainer in the bottom. They are owned by Mr. Alfred R. Clark. The water is reported to be of very good quality; and as there are no buildings above, there is no chance of pollution. The springs are covered with protecting sheds.

There is plenty of water here for all purposes, but some care is necessary not to waste it in dry seasons. Water rates are $6 a year for either one or two faucets. About two-thirds of the houses in the village use the public supply.

PREDICTIONS AND RECOMMENDATIONS.

In an investigation like that of the underground waters of Maine it is gratifying to see that in some districts the value of drilled wells is appreciated. In the vicinity of Portland a number of manufacturing establishments and tenement owners are using drilled wells and

thereby saving water bills. On the neighboring coasts and islands of the harbor there is a large summer population, and these people are using a great many drilled wells. Such is also the case in a few summer-resort districts away from the coast. In general excellent supplies of pure water are obtained, and very few failures have been encountered. The proportion of successful wells shows that there is plenty of water for domestic use in the rocks, although the supply is not always sufficient for hotels. As might be expected, there have been a number of failures, but the chance of success in any locality is far greater than the chance of failure. Drilled wells are so much safer and so much more satisfactory when an adequate supply is found that it would seem desirable to search for water in this way much more extensively than has been done.

The success of well drilling in the vicinity of Portland has been so marked that it seems safe to recommend sinking wells on islands of the harbor where as yet they have not been drilled. For example, on Long Island the residents are using the common open wells, as of old. A number of people on Peaks Island and some of the other islands use wells of the same type. These may be safe in the country, but are hardly safe in a summer-resort island having a large population. A public water system could be installed on other islands at a comparatively small cost, as has been done on Peaks Island and Great Diamond Island. The water obtained by deep wells will be safe for drinking, and three or four wells will probably give a sufficient supply for any of the largest islands.

It may not be amiss to emphasize in this connection a precaution regarding Sebago Lake water, to which reference was made on pages 109–110. This lake has for years been supplying the city of Portland and several adjacent towns, and the water has been found to be one of the best surface supplies in the State. There is more water than can ever be utilized, and the lake is so large that contaminated water now entering any particular part of it would be so diluted as to cause little danger to the inhabitants of the city. It must be remembered, however, that there are already a number of cottages and hotels along the shores of Sebago Lake and its tributaries, and that these are springing up more thickly every year. At least two steamboat lines run on the lake regularly, and it is used for fishing and bathing. Every precaution should therefore be taken to keep the lake in a sanitary condition and to prevent the increase of cottages and hotels along the shores. The best plan would be for the city or the State to acquire and hold the lake as a public reservation in care of a park commission, as has been done with several large reservoirs in Massachusetts and other States.

SOUTHERN FRANKLIN COUNTY.

GENERAL DESCRIPTION.

Franklin County is situated in western Maine, its north end bordering on the Canadian line and its west end separated from New Hampshire by a distance of about 12 miles. The county has a length from north to south of about 85 miles and an extreme width of 30 miles. Its total area is 1,764 square miles, and its population, according to the census of 1900, was 18,444, the least next to Piscataquis County. This county contains no cities or large towns; Farmington, the county seat, has a population of 1,251. Less than two-thirds of the county is situated in the territory covered by this report, but the region farther north contains few features of importance to a report of this nature. The county is one of the hilliest in Maine, and contains numerous lakes and ponds, of which the largest situated entirely within the borders of the county is Rangeley or Oquossoc Lake. A large lake, Mooselookmeguntic, lies on the boundary between Franklin and Oxford counties. A stretch of Androscoggin River, less than 5 miles in length, cuts across the southern corner of the county, and Rangeley and Mooselookmeguntic lakes lie near the headwaters of the same river, but with these exceptions there is no large stream within the borders of the county. Sandy River, a tributary to the Kennebec, flows through the south-central part of the county, and Dead River, with its numerous lakes and small tributaries, is a conspicuous feature of the north end of the county, which is far famed for its fishing grounds. In altitude Franklin County ranges from 355 feet on Androscoggin River near Chisholms Mills to 3,388 feet at the summit of Mount Abraham. The central part of the county is very mountainous, and contains few villages and few lines of transportation. The Maine Central Railroad extends as far as Farmington, through a fairly settled district, but the region north of Farmington is reached only by the Sandy River, Phillips and Rangeley, and Franklin and Megantic railroads, narrow-gage lines, which extend north as far as Carrabasset and northwest as far as Rangeley and several summer camps, the latter of which are reached by unimportant branches. Rangeley and Mooselookmeguntic lakes are also reached by the Portland and Rumford Falls Railway, which runs northward from Rumford Falls, in Oxford County, as far as Oquossoc, on the western edge of Franklin County. A map of this county showing the distribution of deep wells, important springs, and communities having public supplies forms Pl. XIII. This report considers only the region south of the forty-fifth parallel.

0 5 10 20 MILES

MAP OF SOUTHERN FRANKLIN COUNTY.

Showing distribution of deep wells, important springs, and communities having public supplies.

UNDERGROUND WATERS.

RELATION TO ROCKS AND SURFACE DEPOSITS.

Distribution of rock types.—The rock formations of Franklin County are not well known, but are supposed to consist almost entirely of granite and slate, with slate predominating. An area of granite enters the southwest corner and crosses the county in a northeast direction, the band having a width averaging less than 10 miles. This granite is quarried at Jay, on the Maine Central Railroad. It does not extend north of Dryden. A small granite area enters New Sharon from the east and heads for the area in which Jay is situated, indicating that these two areas may be connected at no great depth below the surface.

The known distribution of the rocks in this county can probably be best described by stating the areas in which they cross the several lines of transportation. North of the most northern outcrop at Dryden, on the Maine Central Railroad, the formation is entirely slate as far as Strong, on the Phillips and Rangeley Railroad. In the vicinity of Phillips, however, there is a patch of granite several miles across. Beyond Phillips no more granite is encountered until the railroad turns west, just north of East Madrid, in the mountain region. An area of granite is crossed here for about 10 miles, beyond which the rocks are slaty as far as Rangeley. Rangeley Lake is situated entirely within the slate area, but from this lake southward, along the Portland and Rumford Falls Railway, the formation is granite as far as Houghton, just beyond the borders of this county. On the Franklin and Megantic Railway the formation is supposed to be entirely slate from Strong—the junction of the Phillips and Rangeley and Sandy River railroads—northward as far as Carrabasset. Here, however, an area of granite is entered and continues to the end of the railroad at Bigelow. The village of Stratton, 7 miles northwest of Bigelow, is situated in the granite area. West of Stratton, however, the rocks are believed to be slaty in nature. In the extreme northern part of Franklin County, extending from a point near Beaverpond as far as the Canadian border and westward to the Oxford County line, is another area of granite. As a great part of Franklin County consists of wilderness, the detailed geology of this county is unknown.

Surface deposits.—In Franklin County the drift deposits are generally thick in the valleys and very thin in the hills. On Sandy River and some of the smaller streams there are extensive sand plains of unknown depth. In the vicinity of Farmington these are underlain at a few feet by clay, probably an extension of the same clay deposit which follows Kennebec River for so many miles. Irregular sand and gravel deposits are widespread over the county and are generally underlain by bowlder clay, which also forms the surface over much of the uplands.

WELLS.

GENERAL DESCRIPTION.

Franklin County is so well provided with springs that wells are less numerous than in other parts of Maine. Dug wells are, however, common in the valleys, especially in the southeastern part of the county. The general depth of the dug wells is from 10 to 30 feet, though a few are more than 40 feet in depth. They are mostly sunk in drift, but a few wells have been blasted in rock. Most of the wells in this county give plentiful supplies of water, and, as the population is not large, few wells are contaminated. No drilled wells are known to have been sunk in the county.

DETAILED DESCRIPTION.

Farmington.—The town of Farmington, the county seat of Franklin County, is situated on a sand plain bordering Sandy River and high above it. It formerly had a public supply from an infiltration well situated 30 feet from the river. As this did not furnish sufficient water for the village, a portion of the supply was drawn from the river. Most of the inhabitants used this water until recently, and few people in the village have wells. The supply is now derived from Varnum Pond. On the outskirts of the village are situated many dug wells, one of which reaches a depth of 58 feet. This well is reported to pass through 10 or 15 feet of sand, underlain by clay, which extends to the bottom of the well. It contains about 50 feet of water the year round. That the clay underlying the sand is very irregular in elevation is shown by a road section southeast of town in which the clay rises sharply through a height of 15 feet or so and reaches the general level of the plain. Between Farmington and Farmington Falls attempts have been made to drive wells in the clay, but all trials have failed, owing to clogging of the screens by fine clay particles.

With the foregoing exception the wells at Farmington are mostly less than 25 feet in depth and few exceed 35 feet. They are dug in sand and gravel and generally rest on clay. The rock in the vicinity is a dense slate, striking northeast and southwest and having a vertical dip. Between Farmington and Strong the supplies are derived mostly from springs, as the hillsides are steep and spring water is generally easily obtainable.

SPRINGS.

General statement.—As Franklin County is very hilly, it has numerous springs, and it is not likely that there will ever be any serious lack of water except locally. Springs are used by many families in the country districts for domestic supply, and at least two villages use them for public supplies. Within the county are

at least three so-called mineral springs, one of which ships water regularly by railroad, and a second has done so in the past. These springs are as follows:

Carrabasset Mineral Spring, Carrabasset.
Knowlton Soda Spring, Strong.
Rangeley Mineral Spring, Rangeley.

Carrabasset Mineral Spring.—Carrabasset Spring, belonging to the Carrabasset Mineral Spring Water Company, of Boston, is situated on the bank of a small stream 10 feet above water level, on the Franklin and Megantic Railway, a short distance south of Carrabasset station. It issues near the base of a sand plain which rises only 10 feet higher at its central point, about 250 feet away. The spring was formed by digging a well 15 feet deep to a soft, shalelike rock. The water is reported to come from the rock. It is colorless, odorless, and tasteless, and has a temperature reported to be 46° in summer and 42° in winter. The flow is 5 gallons a minute after a storm and 2½ gallons a minute during a dry spell. It is said that after a heavy rain an hour or so elapses before the spring is affected. The water is used for drinking at a farm and two cottages situated near by and is bottled and shipped to Boston as a table and medicinal water. The price is 25 cents a gallon, or $1 for a 5-gallon bottle. A part of the water is carbonated. The company runs a bottling establishment on the spot, and the spring is well protected by curbing on all sides. An analysis of the water, recalculated from that published in the company's circular, is reported in the table (No. 230).

Carrabasset Spring No. 2.—Not far from the Carrabasset Mineral Spring, on the opposite side of the river, is a spring, owned by the same company, which issues from the side of a high eskerlike ridge. The analysis of this water is given in the table (No. 231). No water is yet shipped.

Knowlton Soda Spring.—The mineral spring belonging to Mr. R. W. Knowlton is situated in South Strong, 7 miles north of Farmington. According to the owner, the spring emerges from a rocky hillside at the rate of 8 gallons a minute. It is reported by the owner to have valuable curative properties. The spring is covered by a three-story building, where the water is bottled. An analysis, recalculated from an analysis furnished by the owner, is given as No. 235 in the table.

Rangeley Mineral Spring.—The Rangeley Mineral Spring is owned by the Rangeley Lake Hotel Company, and is situated a short distance from the Rangeley Lake House, on a gentle bowlder-clay slope at least 50 feet above the highest part of the town of Rangeley and 60 feet or more below the crest of the hill. The

water seeps out of the hillside in a small stream. It has no color, odor, or taste and is very cold. As the spring house is always closed, the volume of flow could not be measured. The water is piped through a 1½-inch pipe to the Rangeley Lake House, where it is used for all drinking and cooking purposes. It has sometimes been shipped to Boston. No improvements have been made, with the exception of digging out the spring to a depth of about 8 feet, stoning it up with bowlders from the field, and building a small spring house over it. The water has been used since the hotel was started in 1896. It is probable that many other springs of good quality could be obtained on the same hillside. The analysis reported by the owners of the spring, recalculated into ions and parts per million, is given in the table (No. 234).

PUBLIC SUPPLIES.

General statement.—In Franklin County public water supplies are not common. Several towns, including Farmington, Phillips, Rangeley, Strong, and Kingfield, use water from surface sources. Farmington Falls has a supply from springs.

Farmington Falls.—The water system of Farmington Falls is a gravity supply from springs situated in sand and gravel hills near the town. These springs have been in use for about thirty years. No pumping is necessary, and the water is brought to town in a 1-inch pipe, which is lead except where it crosses the river, that portion being made of iron. The system is owned by the Farmington Falls Aqueduct Company, consisting of thirteen shareholders, who paid $100 each at the time of its establishment. These persons and four other families use the water for domestic purposes, the four outside families paying $8 a year each. The water is of excellent quality and never gives out, but in dry seasons it is occasionally rather low. A field assay resulted as shown in analysis No. 233 of the table.

Strong.—The Strong Water Company was installed in 1905 to supply the village. The wells in town had been satisfactory, but it was thought advisable to put in this supply for the sake of the additional conveniences. The water is taken from a small pond a few acres in extent situated on the slope of the mountain west-southwest of Strong. There are 75 faucets and 12 fire hydrants in the village, and seven-eighths of the people are said to use the public supply. The pond is reported to be 600 feet above the village. It gave at first a pressure of 200 pounds, but now it has been regulated to 80 pounds, which is sufficient. This water, from a high source on the mountain, is excellent in quality.

Rangeley.—Rangeley has a public water supply from Cascade Brook, on the flanks of Saddleback Mountain. The water is good; but, notwithstanding this fact, about half the inhabitants use dug

wells 10 to 30 feet in depth. The Rangeley Lake House has a fine supply piped to the hotel from a spring on the hill. Other springs could be obtained and used if desired, but the present public supply seems entirely satisfactory.

Kingfield.—Previous to 1898 the village of Kingfield used dug wells 10 to 25 feet in depth, and typhoid fever was prevalent. In that year a public supply was installed from Tufts Pond Brook, and the typhoid suddenly disappeared. The water is now excellent and few wells are used.

PREDICTIONS AND RECOMMENDATIONS.

The water supplies of Franklin County are so uniformly excellent that suggestions regarding their improvement may be considered unnecessary. Several villages, however, of which the largest is Rangeley, draw water largely from dug wells situated within their limits. In all such villages no time should be lost in installing a system of waterworks, either from some mountain brook of which the water is perfectly safe from pollution, or from springs, or drilled wells, or other safe wells. As yet no deep wells have been drilled in Franklin County. The reason is obvious—they have been unnecessary in most places. In towns like Rangeley and Farmington, however, which have not entirely satisfactory systems of waterworks, it would be possible to obtain water by drilling wells through the gravels and underlying clays into the bed rock, and such supplies would be safer for drinking than the ordinary dug wells situated within the town limits.

HANCOCK COUNTY.

GENERAL DESCRIPTION.

Hancock County lies in southeastern Maine, bordering on Penobscot, Bluehill, and Frenchman bays and including a large number of islands. Its western edge is formed by Penobscot River. This county is about 90 miles in extreme length from north to south, about 50 miles in greatest breadth, and has a total area of 1,390 square miles. According to the census of 1900 its population was 37,241. The largest city is Ellsworth, with 4,297 inhabitants, but Bar Harbor has a large summer population and is an important place during a few months of the year.

Hancock County can be said to consist of three sections—the island region and the adjacent inhabited region, which together comprise about one-half of the area, and the wild lands, which make up the other half. The wild lands are confined to the area lying north of the Maine Central and Washington County railroads, which cross the center of the county. The only other transportation line on land is a branch of the Maine Central Railroad which enters Bucksport, the

northwesternmost town in the county, from the north. The surface configuration of Hancock County is very diverse. Much of the coast is low and consists of gently sloping rock ledges or of clay or bowlder-clay plains, but on Mount Desert Island many of the cliffs are precipitous, and there are mountains that rise to an extreme altitude of about 1,500 feet. Inland from the coast, especially in the region situated north of the railroads, there are many mountains, some of which reach elevations as high as 1,200 feet. Throughout the county are scattered numerous lakes and ponds. A map of this county showing distribution of deep wells, important springs, and communities having public supplies forms Pl. XIV.

The water conditions of Hancock County vary greatly. Away from the coast most of the wells are dug wells, which give fair supplies. On the coast and on many of the islands, however, water is harder to obtain and drilled wells are the rule, especially in the summer resorts.

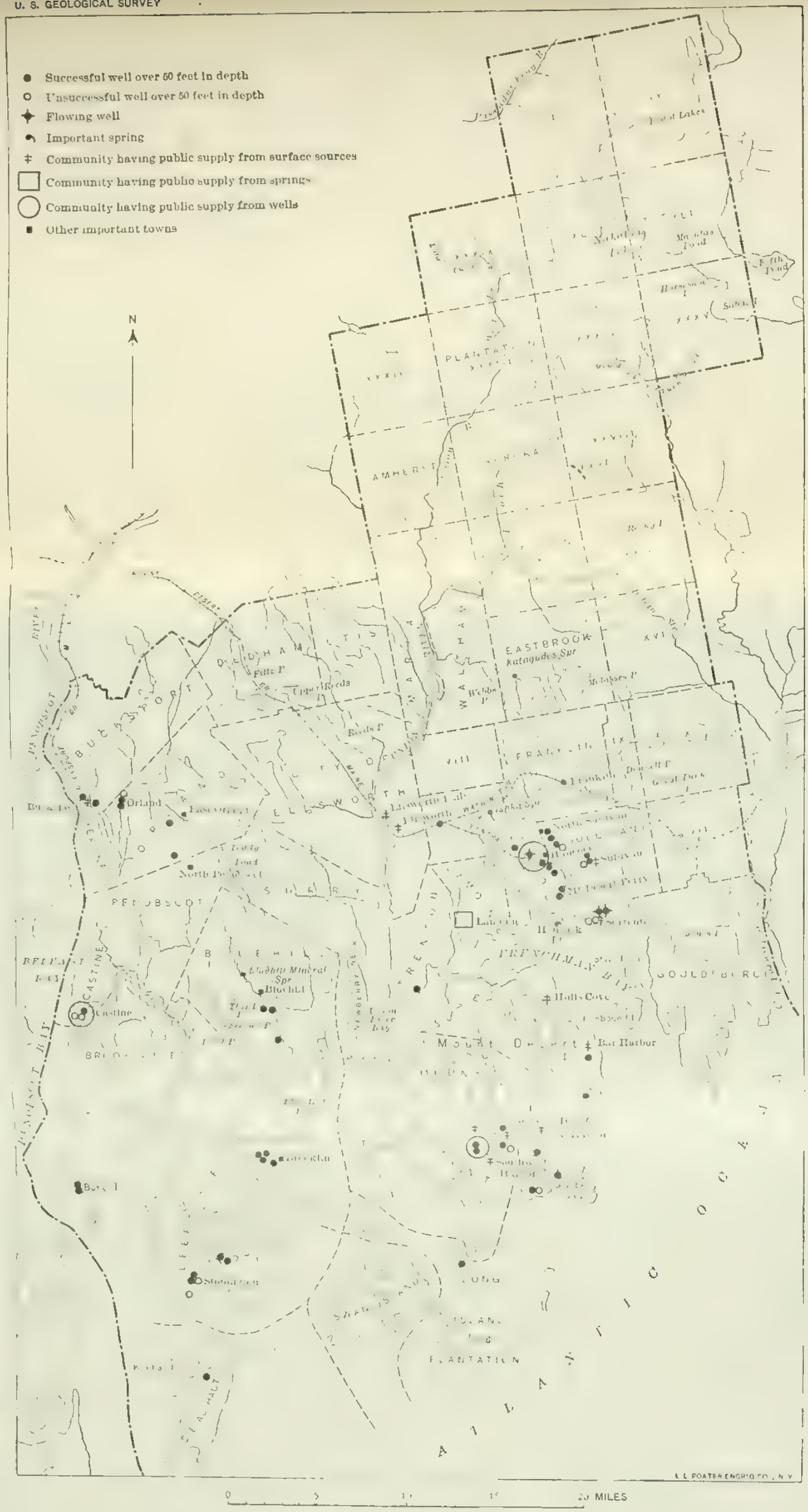
UNDERGROUND WATERS.

RELATION TO ROCKS AND SURFACE DEPOSITS.

Distribution of rock types.—The prevailing rock in Hancock County is granite, which, however, is irregularly distributed. It forms the greater part of the islands, although the northwestern part of Deer Isle, the coasts of Mount Desert, and many smaller islands are composed of other rocks. Castine, Brooksville, Sedgwick, and Penobscot are underlain in part by volcanic rocks. With the foregoing exceptions the area west of Ellsworth is granite. The towns of Ellsworth, Hancock, Lamoine, and Trenton, and a strip extending northward with an average breadth of 5 to 10 miles, supposedly as far as Amherst and Aurora, are underlain by slate and schist. Another small patch of slaty rock lies in Sorrento and the southern part of Sullivan and Township VII, in the southeast corner of the county. North of this area and covering the two eastern tiers of towns in the county an area of granite extends to an unknown distance, probably nearly to Great Pond. The north end of the county, within the area under consideration, is known to consist of slate, but north of the forty-fifth parallel lies another area of granite.

The structure of the granite of Hancock County is typical of Maine granite in general, as described on pages 29–32. The area mapped and described as granite in this part of Maine includes, however, small areas of diorite ("black granite") and similar rocks.

At Hall's quarry on Mount Desert, at Stonington, at Sullivan, and at Vinalhaven the granite is extensively quarried, and numerous exposures at these places show water seeping out of the sheet joints, as explained on page 31 and illustrated in Pl. III. At one place, near Stonington, a good spring issues from a vertical joint crack on



MAP OF HANCOCK COUNTY.

Showing distribution of deep wells, important springs and communities having public water supplies

the hillside. The direction of the joints is variable, but the majority of them trend between N. 75° E. and S. 50° E. Their size is small, but they seem to hold plenty of water in places.

The slate in Hancock County is extremely variable in character, at some places being hard and blue and at others consisting of a very metamorphic schist, much contorted and containing locally a large amount of iron and other minerals. In places, as at Bucksport, the slate becomes very hard, dense, and quartzitic.

The detailed distribution of the rocks in a small section of southern Hancock County has been worked out by G. O. Smith, E. S. Bastin, and C. W. Brown, of the United States Geological Survey, and hence it is possible to describe the formations of this region somewhat more fully than those of others. A considerable part of the area is granite, but the intervening regions are occupied by other igneous and stratified rocks distributed very irregularly. The distribution of the formations that have been mapped by the geologists in detail is described under the various townships.

Surface deposits.—The surface deposits of Hancock County are extremely variable in character and thickness. In Penobscot, Bluehill, and Frenchman bays the coast of the mainland and islands consists mostly of bare rock and the smaller islands are covered only with a thin coating of drift. In a few areas protected from wave action along the coast low clay plains are found, and in several places in Bluehill and vicinity low drumlin-like deposits of bowlder clay occur. On the larger islands and on the mainland away from the coast the drift is of considerable thickness. The bowlder clay is generally 5 to 50 feet or more thick, and in the valleys it is commonly overlain by sands, gravels, and clays. At Orland a cliff of bowlder clay rises 100 feet vertically above tide water of the river. In exceptional cases bowlder clay is underlain by sand, as in the well of Mr. Tom Mason, near East Orland.

WELLS.

GENERAL DESCRIPTION.

Types of wells used.—Certain parts of Hancock County are abundantly supplied with water from springs, but wells are generally more abundant on the coast and on the islands. Old-fashioned dug wells are common, and in many of the country districts are preferred by the inhabitants on account of the large amount of water contained in the drift. A few driven wells have been sunk through sand and clay in certain localities, and some of these have discovered small artesian supplies.

Drilled wells.—Along the coast and on the islands the most popular and best type is the drilled well, of which more than 170 have been

sunk to depths exceeding 50 feet. The prevailing size used is 6 inches and the depth varies from 30 to 675 feet. Most of the drilled wells in the county have been successful in obtaining fair amounts of potable water. A few have been failures owing to the absence of sufficient water or to the penetration of salt water into the wells. The failures have been commonly in schist and metamorphic rocks, seldom in granite. Where little water is found the difficulty is probably due to the fact that the wells did not chance to strike a fissure containing water. Another well near by might meet with success. As the greatest amount of water in the rocks is held comparatively near the surface, it is seldom advisable to drill below 200 feet or so. Instead, if a well reaches that depth without obtaining water, a second attempt should be made 50 to 100 feet away.

Quality of water.—The quality of water in Hancock County is extremely variable, owing largely to differences in the character of the formations. An example of the nature of waters which are generally obtained from deep wells in sand is shown in No. 184 of the table (p. 83), where the total solids are seen to be only 66 parts per million. Several dug wells in till have been tested by field assays in Orland, Eden, and Sorrento, and are low in mineral content. The amount of chlorine in some of these wells indicates possible pollution.

The wells in granite, of which four laboratory analyses have been made, give total solids from 81 to 364 parts, the lowest amount being found in a well on Greenings Island near Southwest Harbor, and the highest in the Crabtree & Havey well at North Sullivan. The chlorine in these four wells varies from 17 parts in a well at The Settlement, Stonington, to 140 parts in the Crabtree & Havey well. As these are deep drilled wells, not subject to pollution, the chlorine is probably a natural constituent of the rock. Sulphates range from a trace up to 25 parts per million, with one report of 104 parts. Carbonates run from 8 to 70 parts, and calcium, magnesium, sodium, and potassium are present in moderate amounts. In several analyses a little iron is reported, but this is not generally found in granite. The analyses of granite waters in Hancock County are tabulated on page 77, Nos. 9 to 19.

Three complete analyses have been made of waters in slate in Hancock County (Nos. 55, 56, and 57). One is from a 308-foot well in the village of Bucksport, the second is from an open well a few feet distant, and the third from a well in Hancock. The first two of these analyses show 116 and 53 parts per million of total solids, respectively. An interesting feature regarding these wells is that while the water of the deeper one is more than twice as high in total solids as that of the open well, the chlorine is the only constituent which is highest in the latter. This feature is strong evidence of pollution in the open well. Water from a slate well in the village of

Orland contains a little iron, and much iron is known to be contained in schists in some parts of the county. Near North Penobscot a well so situated is so strong in iron as to be almost useless.

Many wells along the coast have been ruined by the entrance of salt water from the sea. This occasionally happens in granite, but is much more common in slate. An example in the town of Sorrento is described on page 67.

Quantity of water.—Although it is unsafe to depend on the figures given by well drillers and owners as a guide to the amount of water likely to be furnished by a well, they are of some use as a general guide to the amount which may be expected. Wells in this county report all yields up to 100 gallons a minute, those commonly reported being only 3 to 5 gallons a minute, which, however, is plenty for all domestic purposes. A few wells gave too little water to be used. Most of the drilled wells hold out from year to year, when sunk deep enough, but dug wells often run dry. In a drought several years ago many of them gave out.

Uses.—The water of wells in Hancock County is used mainly for domestic supplies, and drilled wells are fairly common at summer cottages. In Castine, Southwest Harbor, Sorrento, and Stonington, however, they have been sunk for public supplies. At Sorrento a driven-well system has been abandoned for a surface supply, and the Stonington well was never used. At Hancock Point an abandoned mine shaft is used for public supply. At Brooklin a canning company has a drilled well; at Stonington granite quarries use them. The wells of Hancock County are commonly operated by hand pump, but many are rigged with windmills and a few are pumped by steam, gasoline, or hot air.

Flowing wells.—Several flowing rock wells are known in Hancock County. A number at Hancock flow from a bed of gravel confined underneath clay, and a similar local basin is situated near the village of Sorrento.

DETAILED DESCRIPTIONS.

Ellsworth.—As Ellsworth has a satisfactory public supply from a pond, very few wells are now in existence in the city. There are no drilled wells. The rock formation is slate and schist, and as drilled wells in these rocks are generally successful elsewhere it is probable that here too they would meet with success. At Ellsworth Falls water can be seen seeping out of joint cracks in slate, and this indicates the availability of water for wells in these rocks.

Bluehill.—The part of the town of Bluehill lying northeast of the village and extending nearly as far as North Bluehill, the region lying southwest of Bluehill Falls and extending eastward to South Pond, and a small section in the extreme northwest corner of the

town are underlain by granite. A strip just east of the granite area, in the western part of the town, consists of diorite, diabase, and gabbro. Long Island is made up of granite as far north as Deep Cove; otherwise this town, including the north end of Long Island, the whole of Bluehill Neck, the vicinity of Bluehill village, and North Bluehill, is composed of schist.

Several deep wells have been drilled in this town to supply summer cottages along the shore. Dr. A. M. Thomas has a well 140 feet in depth, in gneiss. Unfortunately the water is very turbid, owing to the entrance of clay through crevices in the rock. The supply is sufficient, as the water can not be lowered by pumping and yields 2,500 gallons in three or four hours per day, but on account of its quality it can be used only for the stable. The well belonging to Mrs. Ethelbert Nevin at Bluehill Falls is reported to yield 7½ gallons of water a minute. On account of the great amount of iron contained in the rocks over large areas in the town of Bluehill, it is probable that some wells here will fail to get water. Analyses made of the two above-mentioned wells did not, however, show any iron. The amount of carbonates was high for Hancock County, being 92 and 110 parts per million, respectively. Where the rock consists of granite, gneiss, or hard, compact slate the water will generally be of good quality. In the vicinity of Bluehill village most of the wells are dug to ledge and some are blasted, getting good water. Bluehill Mineral Spring is situated in this town.

Sedgwick.—The town of Sedgwick is nearly all underlain by granite. In the southern part of the town, extending from Benjamin River westward along the coast to the Punchbowl, is a strip of volcanic rocks. Between the villages of Sedgwick and North Sedgwick stretches another strip, which consists of schists. In the vicinity of Bluff Head is a small area of schist, and between Bluff Head and the northern corner of the town lies a small area of diorite.

No drilled wells are known in Sedgwick. The dug wells are 8 to 20 feet in depth, and most of them get plenty of water in drift. A few run dry in summer. The water is commonly of good quality.

Brooklin.—The portions of Brooklin lying south of Brooklin village, and including the end of Flye Point and the islands of the town, are granite. North of Brooklin village the town is entirely underlain by schist.

Several deep wells have been drilled in the vicinity of the little settlement known as Haven. These are from 50 to 112 feet in depth and find plenty of water that is reported to be of good quality for domestic purposes. One of the wells here, owned by Noah V. Tibbitts, is reported to supply 20 cottages. This well is 87 feet deep, and a number of veins of water were found. A drilled well of the Brooklin Packing Company supplies a sardine factory and near-by houses.

Castine.—The rocks of the peninsula of Castine are entirely volcanic, and consist mostly of a stratified variety known as tuff. The village of Castine is supplied with water chiefly from deep drilled wells, but in part by springs. Many people continue to use dug wells, which generally yield plenty of water, but which, being situated in the heart of the village, are clearly subject to contamination. The Castine Water Company has four wells, 58, 70, 80, and 110 feet deep, situated on one of the highest hilltops of the peninsula. On another hilltop a well 675 feet in depth was drilled by the same company. This is an 8-inch well and one of the deepest in Maine. The first water was found at 425 feet and rose within 25 feet of the well mouth. The well is reported to yield about 13 gallons a minute through the day, but is not very satisfactory on account of its poor construction. Further data regarding these wells are given under "Public supplies" (pp. 147–148). The fact that the last-mentioned well was sunk to a depth of 425 feet without striking water indicates that wells in this section will probably not all be successful. This statement is emphasized by the result of the well drilled for the Acadian Hotel Company on the hillside on which Castine is built. In July, 1906, this well was down 227 feet and the test with the hand pump showed a yield of only about 1 gallon of water a minute. As the owner did not consider the yield sufficient, he was advised to discontinue this well and start a new one a short distance away.

Bucksport.—At the Eastern Maine Conference Seminary, Bucksport, a well was drilled to a depth of 308 feet. Water was struck at about 100 feet and a second seam at about 300 feet. In the spring of the year when it was drilled water overflowed the surface, and the well supplied several gallons a day of excellent water. It is pumped by a 3-horsepower gasoline engine. Analyses of water from this well and from an open well a few feet distant are given in the table (Nos. 55 and 56). It is interesting to note that all the constituents are higher in the deep-well water than in that from the shallow well, with the exception of chlorine, which is higher in the open well. This indicates the probability of contamination in the open well. In another part of Bucksport two wells, 30 and 80 feet deep, were drilled only 3 feet apart, in quartzite, and connected by blasting. Only one of these is pumped. The supply is not large, but is sufficient for domestic purposes.

Orland.—In the town of Orland several drilled wells have been sunk, with varying results. The best well in town was that drilled for Mr. Tom Mason at East Orland. This well started on a gently sloping hillside consisting at the surface of bowlder clay containing numerous large bowlders. Instead of striking rock at a few feet, as might have been expected, the drill went through 87 feet of sand and gravel and then struck an excellent supply of water directly on

top of a bed of clay. The water is clear and cold, and 8 gallons a minute can be pumped. The well is very low in mineral matter, as shown by analysis No. 184 in the appended table.

A well drilled for Mrs. A. W. Hutchins, near North Penobscot, was not so successful. The rock is here a hard, traplike formation containing a considerable quantity of iron. This well was dug 12 feet in bowlder clay, blasted 8 feet through ledge, and then drilled 57 feet, making a total of 77 feet, striking water at 67 feet. The water tastes very strongly of iron. (See analysis No. 59.) It can not be used for washing because it stains everything with which it comes into contact, and iron is precipitated from the water when it is left standing for some time.

At the village of Orland three wells have been drilled to depths varying from 40 to 70 feet. One of these was abandoned because of the large amount of iron contained in solution and the supposed connection of the well with the river. A second well gives plenty of water, which has a slight iron taste, but not enough to interfere with domestic use of the water. The quantity of iron is not more than half a part per million, and the other minerals are low, as shown by a field assay (No. 58). That the water is highly prized is shown by the fact that eight families use it in seasons when the surrounding dug wells run low. The water is reported to be softer than when the well was first drilled, seventeen years ago. This well is situated on a point of rock which projects into the river and on which a number of cottages have been built. Across the river the formation is quite different, a steep bluff of bowlder clay being exposed for a height of about 100 feet. It is improbable that much water could be obtained from this material. Throughout the town of Orland dug wells are the prevailing type. They do not often give out, but frequently get very low. Where not polluted the water is of good quality. An example of the quality of water in till is given by a field assay (No. 170). The well from which this water was taken supplies six to eight families during a drought. Generally, however, water is not so abundant in till.

Stonington.—The wells of Deer Isle are all open wells except in the vicinity of Stonington, where a number of drilled wells have been sunk. At Stonington the sanitary conditions are very poor, only five wells having been drilled; the rest of the people use dug wells and springs, the water of which is polluted and dangerous. The town is thickly settled, is growing rapidly, and has no sewerage system. The formation is entirely granite, and hence the results obtained in drilling here have a rather important bearing on the occurrence of water in granite in general.

Two of the most successful wells in the region were drilled in 1906 at Mr. J. C. Rogers's quarry at "The Settlement" to supply water

for quarrying operations. The first well was 93 feet 8 inches in depth, passing through 27 distinct "beds" of rock. The thickest mass of rock uninterrupted by joints measured 14 feet, but some were only a few inches in thickness. The thickest bed was encountered about midway from top to bottom of the well. This well supplied 62 gallons of water in seven minutes, but the supply was not considered sufficient and a second well was drilled 50 feet distant. It was sunk to a depth of 279 feet and intercepted the same water-bearing fissures as those found in the first well, as was proved by the fact that pumping the second well lowered the water in the first. A week's test was made on these wells. They are said to connect 60 feet below the surface, and will yield 60 gallons a minute. A field assay of the water of the first well and a laboratory analysis of that of the second are given in the table (Nos. 18 and 19).

In the village of Stonington Mr. Samuel Goss has a well 67 feet in depth, also drilled in granite, which supplies his hotel. A field analysis of this has been made (No. 15). The Goss well supplies also fifteen or twenty families, and the water is used for watering lawns, etc. Ten years ago the Pine Lake Water Company sunk a well on the summit of Thurlow Hill, near the village, for the purpose of procuring a public supply for the village. The well was drilled to a depth of 183 feet, and is reported to have yielded 18 gallons of water a minute, but was plugged and has never been used. The Guyer & Torey well was drilled to a depth of 67 feet to supply two families, and a windmill and tank were installed and pipes run to the houses before it was discovered that the supply was too small to be used. The Sunset House, Acadian House, and a dozen residences are supplied by a good spring situated on a hill outside the village. The result of a field assay of this water is given in the table (No. 240).

In one quarry at Stonington the approximate amount of water issuing from the granite can be calculated from the amount pumped out of the quarry. The writer was informed by the foreman that more than 3,000 gallons accumulate daily in the bottom of the quarry from the joints. Near this quarry a good spring issues from a vertical joint which is said to be as wide as a common pencil. The crack is situated on the hillside below the quarry, but as it was covered it could not be seen.

One of the difficulties in quarrying granite on the smaller islands near Stonington is lack of water. On Moose Island there is a small catchment area consisting of a swamp, and water is obtained from a dug well near by. On Crotch Island the quarry of the Ryan-Parker Construction Company is 130 feet in depth, mostly below sea level, and is nearly dry. In a search for water another well was drilled to a depth of 300 feet, but without success, except that salt water was encountered. The chlorine in this well was 70 parts per

million and the sulphates 104 parts. (See analysis No. 17.) In 1907 a second attempt was being made for water on the opposite side of the island. No other drilled wells have been sunk in the vicinity of Stonington.

On Deer Isle there is a good chance of getting water at moderate depth. On the smaller islands, however, conditions are less favorable and as a rule drilling will probably not pay. In the vicinity of Stonington there is very little drift overlying the granite, and this circumstance probably explains why so little water is found by drilling on the smaller islands.

Deer Isle.—About half of Deer Isle, comprising the area lying east of a line drawn from Smalls Cove through Deer Isle village and Torry Pond to Eggemoggin Reach, consists of granite. This area also includes the islands lying in that part of the town. West of the above-described line the major portion of the island consists of acidic volcanic rocks. There are one or two small patches of schist in the northern part of the island and several areas of greenstone west of Deer Isle village. The wells on this island are dug in bowlder clay and the depth of the deepest is 28 feet. The amount of water is extremely variable.

Little Deer Island consists of volcanic rocks and small areas of associated formations. The other islands of the town of Deer Isle in Penobscot Bay are made up almost entirely of volcanic rocks and greenstone. No drilled wells have been sunk. From the variability of the rocks a broad range may be expected in the character of the well waters.

Swans Island Plantation.—Swans Island consists entirely of granite. No drilled wells are known to have been sunk.

Long Island Plantation.—There are several islands in Long Island Plantation, but the only one on which a well is known to have been drilled is Black Island. This well was sunk to supply the granite quarries, but the water is also used for domestic purposes. The depth is 78 feet, and it is reported to be a good well.

Eden, Mount Desert Island.—Mount Desert Island consists of three towns—Tremont, Mount Desert, and Eden. Bar Harbor is situated in Eden, Northeast Harbor is situated in the town of Mount Desert, and Southwest Harbor is in Tremont. The coasts of the island are generally high and rocky and much wave worn. The water supply of Bar Harbor and Hulls Cove is derived from Eagle Lake and is one of the best supplies in the State. At the fair grounds near Bar Harbor a well belonging to Gen. Edward Morrell obtained an abundant supply of pure water at a depth of 87½ feet, in granite. A large number of cattle are watered every day, but the supply never gives out. A field assay of this water is reported in the table (No. 9). As Bar Harbor has one of the best lake supplies and filter galleries in the

State, there is little need for sinking wells in this village. A number of cottages at Schooner Head and vicinity have a supply brought in pipe from The Bowl, high up on Newport Mountain. Near Bar Harbor is a mineral spring known as Red Rock Spring.

At the village of Otter Creek, 5 miles south of Bar Harbor, two wells were drilled to depths of 25 and 37 feet, obtaining small amounts of water, in granite. If they had been sunk 50 to 100 feet deeper the supply might have been sufficient. The first of these wells was drilled to a depth of 25 feet, striking a vein sufficient in quantity for drinking but not for other purposes. An attempt to deepen the well was made by an inexperienced driller, who filled it with loose stones and afterwards lost the drill, and the hole had to be abandoned. A well dug in till in the southwestern part of the town gave the field analysis shown in No. 169. Many fine springs occur in this town.

Tremont, Mount Desert Island.—At Southwest Harbor two wells have been sunk by the Southwest Harbor Water Company. The first successful well was drilled in 1891 to a depth of 125 feet. The second well, 36 feet distant, was drilled in 1899 to a depth of 297 feet. These wells communicate at a depth of 90 feet. They could not be lowered by pumping, but enough water could not be obtained, owing to the insufficient capacity of the pumps in use and possibly also to the inadequacy of the supply, and Long Pond was resorted to as a supplementary supply. A full description of the waterworks is given on pages 148–149.

Many people in Southwest Harbor still use dug wells less than 30 feet in depth. The water is of variable quality. The field assay of a spring which issues from the clay along the shore near the village is given in the table (No. 241). This water flows 3 gallons a minute out of gravel beneath clay, and is highly prized by the owners. The spring is said to be sometimes covered by water at high tide. In the northern part of town is a historic spring, made famous by Indian legends, and the water is highly prized by the residents and visitors. The spring has never been improved. In the villages of Tremont, Bass Harbor, and McKinley only dug wells are used. It is probable that deep wells here would be successful.

Greenings Island, Tremont.—On Greenings Island a well was drilled in 1893 for Mr. J. G. Thorp to a depth of 88 feet, in granite. This well is located only 100 feet from high-tide mark and 20 feet above it. The supply is reported sufficient. The water is pumped to a 5,000-gallon tank for use in the house. (See analysis No. 10.) At the north end of the island the cottages are now supplied by pipes laid under the sound from Southwest Harbor.

Quite different in results from the above is a well drilled at the opposite end of the island about 1903 for Mr. Colton. It is 110 feet deep and salt water was encountered at a depth of 90 feet, where the drill

struck ledge. The water is so salty that it is not used. The drill stuck once or twice in crevices. The occurrence of salt water on this island is not confined to any particular part of the island, but is believed to be largely a matter of chance. A well near this one might be fresh, and, conversely, a well might happen to strike salt water at the north end of the island.

Town of Mount Desert.—Mr. L. E. Kimball, of Northeast Harbor, had a well drilled several years ago for the cottages there and the well was later bought by the water company. It was sunk to a depth of 189 feet. At 90 feet from the surface water commenced to enter the well. Several soft places in the ledge were encountered, and at one place the drill dropped as much as a foot. The water increased in volume with depth, and when the well was finished the test showed 60 gallons a minute for twelve hours, and it could not be pumped dry. The water is good, but somewhat irony. The well was abandoned when the public supply was installed. The rugged character of the town of Mount Desert makes springs very numerous. In the vicinity of Hall's quarry a number of good ones issue from the base of granite cliffs several feet in height. In that quarry considerable water can be seen issuing from sheet joints. At one time enough water for drinking was obtained near the bottom of the quarry.

Cranberry Isles.—On Sutton Island a well was sunk to a depth of 199 feet. This well will yield 20 gallons of water a minute and the water is of good quality. It supplies seven houses on the island.

On Great Cranberry Island a well was drilled in 1904 by Mr. Moorfield Storey to a depth of 201 feet, but it was abandoned, as only a very little water was found. In 1906 a second well was drilled, but the data regarding it have not been received.

On Little Cranberry Island a well 50 feet in depth was sunk for Miss Frothingham. The supply is reported to be 5 gallons a minute.

Hancock.—The village of Hancock is situated on a neck of land which is rather flat and low. A creek flows nearly across the neck and on the lowland lies an area of blue clay ("flat's mud"), below which is sand and gravel. In the square at Hancock, in 1904, a hole was bored with a 2-inch auger, and a strainer was attached to the bottom of the pipe. Below the soil was found a hard blue clay containing fossil shells; below this was a 6-inch bed of fine sand, underlain by coarse gravel containing excellent water, which flowed 9 feet above the surface of the ground. The water will still sometimes rise to a height of 5 feet, but the head is somewhat less than this in dry weather. A dug well near by is not quite so deep, but overflows the surface the year round. The town well averages half a gallon a minute. There are a few other good flowing wells in the vicinity, and most of them are bored. This area is a local artesian

basin, only a few hundred feet across, and the head of the water is caused by the inclination of the gravel bed, which holds the water underneath the clay. The gravel bed reaches the surface east of the wells and is inclined downward toward the west. The wells drilled into the clay but not through it are less satisfactory.

The deepest water supply in the town of Hancock is the village supply of Hancock Point. The source is an old shaft sunk about 1880 for a silver mine. It is 8 feet in diameter at the top and 98 feet in depth. The mine was unsuccessful and was abandoned, and later it filled with water within 4 feet of the surface. The water is said to be of fine quality for drinking purposes until the middle of August in every year, when it is reported to take on a brackish or mineral taste. The water is used only during the summer season.

In the vicinity of Hancock several wells have been drilled and reach depths of 30 to 70 feet. An analysis of the Jeremiah Stratton well, 65 feet in depth, is given in the table (No. 57). A few families use springs. Most of the wells in the vicinity are dug.

Many wells in North and South Hancock are reported to have run dry during the summer following the earthquake shock in March, 1903, while others which were then dry became filled with good water. In a few cases where wet and dry wells stood side by side the one containing water dried up and the other filled with water. Some wells that went dry are reported never to have recovered. Similar instances are reported in the town of Ellsworth. It is probable that the reports regarding these phenomena are correct, but it may be fairly questioned whether the cause was not a dry season rather than the light earthquake shock. The filling up of certain wells may be explained by the slow natural infiltration of water after they have been abandoned for some time.

The supply of the Maine Central Railroad at Mount Desert Ferry is from a spring 2 miles north of the village of Hancock. The Ishka Mineral Spring is situated in this town.

Sullivan.—The village of Sullivan, or Sullivan Harbor, has used water from Long Pond since the spring of 1905. It is good, clear water, but sometimes tastes of algæ. In the past most of the people have used wells or springs, but they are rapidly giving them up for the pond water, which is supposed to be of better quality. Open wells here obtain water in part from drift and in part from rock, and the supply is of variable quality and quantity. Mr. Dwight Braman has a 10-inch well drilled to a depth of 89 feet in granite. The water rises within 8 feet of the surface. It is used for drinking at the Manor House and is reported to have been sold. On the same estate is an abandoned silver-mine shaft, 120 feet deep and 20 by 15 feet in diameter, which is now full of water.

In the same village Capt. S. V. Bennis once had a well drilled 180 feet in depth. This well was 6 inches in diameter at the top and 5 inches at the bottom. The supply of water was small and the well has not been used for thirteen years. The owner reported that the well is drilled in slate which is very dense and contains a great many quartz veins. The Bennis well is situated less than 1,000 feet from the Braman well, and the smaller amount of water encountered in the former may be due in part to the fact that the slate in this locality, as is often the case near granite areas, is very dense, containing few joints, and holds little water, whereas the granite, in which the Braman well was drilled, contains a great many water-bearing joints.

In the vicinity of West Sullivan several shafts of abandoned mines have been transformed into wells. One at West Sullivan was drilled 40 feet and obtained good water, but on continuing it to 61½ feet water which is too highly charged with mineral matter to be used was obtained and the well was abandoned. The surface wells in this vicinity, however, give good supplies of soft water. The public supply of West Sullivan comes from a spring.

At North Sullivan the conditions seem to be much better. The formation is of granite, and a number of wells 50 feet in depth obtained plentiful supplies of as good water as can be found in the State. Some of these wells have been blasted in rock; others were drilled. A comparison of the two types of wells here indicates that for shallow wells in granite the cost of both is about the same, but for deep wells the drilled type is cheaper. For both shallow and deep wells the drilled type is safer.

One of the best wells is that of Mr. C. H. Abbott. This well, after going through 3 feet of drift, struck granite and went to a depth of 136½ feet without obtaining water. On drilling 10 inches deeper a seam of water was struck and a two-hour test was made; in that time 2,000 two-gallon pailfuls were pumped and the water was lowered only 11 inches. In the construction of the well hard galvanized-iron tubing was put down to rock, driven as hard as possible, and cemented to the ledge. With this construction it is impossible for surface water to pollute the well. The assay of this water is given in the table (No. 11). This granite water is a delightful-tasting, clear, cold water. Complete analyses of the Crabtree & Havey well (No. 14) and of the John M. Blaisdell well (No. 13) are given in the table. In the Crabtree & Havey well the amount of mineral matter is very high, being 364 parts per million. A view of the Crabtree & Havey well is given in Pl. V, *B*.

Sorrento.—The summer resort of Sorrento, situated on a peninsula at the southwest end of the town of Sullivan, has a gravity water supply from Long Pond, taking the water from the end of the pond oppo-

site to that from which it is taken by Sullivan. Sorrento formerly had 14 driven wells, installed a dozen years ago, consisting of 2-inch pipes sunk from 50 to 65 feet in depth in gravel deposits a mile northeast of Sorrento. They are reported to have been nearly all flowing wells. They were situated in a low, swampy area a few hundred feet in extent, bordered on the north and south by rock hills and on the east by hills of gravelly till, and a small brook drained out to sea at the west end. Small gravel hills surround the valley, giving a head to the water, which is confined in quicksand below a bed of clay. The wells stretched along an east-west line and were 100 feet or so apart, ranging as much as 50 feet on either side of the center line.

At Sorrento two wells, 92 and 61 feet deep, were drilled in rock about fifteen years ago. Both gave salty water, but one of them was used for a short time. In the rock along the shore are a number of cracks as much as one-half inch in diameter which might allow passage for water into the hill and downward into the wells. The dip is toward the south, and it is probable that the salt water enters the cracks parallel with the stratification of the rock on the north side of the peninsula. Drilled wells are not recommended on this smaller peninsula, but on the major peninsula which juts out from Sullivan they may meet with success. A dug well in till in the northern part of the major peninsula was tested by field assay (No. 171).

Penobscot.—The rocks of the town of Penobscot are also very diverse in character. In the vicinity of South Penobscot, extending northward beyond Wight Pond and southward as far as North Brooksville, the formation is granite, as it also is north of Pierce Pond. Between Pierce Pond and the village of Penobscot, and along a narrow strip just east of Wight Pond, is a band of diorite which encircles the South Penobscot granite area. East of Wight Pond, with the exception of the narrow strip of diorite, the rocks are schist as far as the Bluehill line. West of Northern Bay and south of Wallamatogus Mountain the rocks are volcanic. As in Deer Isle, great difference may be expected in the character and amount of well waters.

Surry.—A strip of granite of variable width extends along the southwestern edge of Surry, but with this exception the region southwest of the village is made up of schist. No drilled wells are known. It is probable, however, that in both the granite and the schist areas drilling will be successful.

SPRINGS.

General statement.—Away from the coast Hancock County is well provided with springs, many of them supplying farmhouses, and some are pumped by windmills. At Greens Pond, in the town of

Dedham, a spring supplies the hatchery and nursery of the United States Fish Commission, and the spring water is piped through the buildings. Within the limits of the county there are at least four important mineral springs, as follows:

Bluehill Mineral Spring, Bluehill.
Ishka Spring, West Hancock.
Katagudos Spring, Eastbrook.
Mount Desert Spring, Bar Harbor.

Bluehill Mineral Spring.—Two springs owned by Greely & Hagarthy, of Ellsworth, are situated in a valley about 3 miles north of Bluehill post-office. The water is reported to issue from a ferruginous rock with a volume of 5 gallons a minute. It is colorless and odorless, but contains some sediment. It is highly charged with iron and other minerals and has deposited iron about its mouth. The analyses reported by the owners and recomputed into ions and parts per million are given in the table (Nos. 236 and 237). The total amounts of solids in the two springs are reported as 79 and 49 parts per million. The water is used for medicinal purposes. The existence of this spring was noticed by Jackson as early as 1838.[a]

Ishka Spring.—The Ishka spring is situated near a hilltop 4 miles north of the village of Hancock. The total solids are reported as 19 parts per million (analysis No. 242). The spring is covered with a house and the water is bottled for shipment.

Katagudos Spring.—The spring known as the Katagudos is situated in the town of Eastbrook, 8 miles northeast of Franklin post-office. The water is said to seep out of a hillside formed of surface deposits, with a volume estimated by the owner as about 8 gallons a minute. The water is said to be colorless and odorless and to have a pleasant taste. It is used for drinking and medicinal purposes and a small hotel is situated there. The owner is Mr. R. B. Lowrie. The analysis of this water is reported in the appended table (No. 238), the composition being recalculated from the analysis reported by the owner.

Mount Desert Spring.—Mount Desert Spring water comes from a spring owned by Messrs. J. H. Souris and C. A. Waters. The water is said by the owners to issue from a fissure in granite. The flow is reported to vary slightly, but to average 12 gallons a minute. Much water is sold in the vicinity and some is shipped to a distance. An analysis, reported by the owners and recalculated from the original into ions and parts per million, is given in the table (No. 239). The water is reported to have medicinal value. The price is 12 cents a gallon.

[a] Jackson, Charles T., Report on the geology of the State of Maine, 1838.

PUBLIC SUPPLIES.

General statement.—In Hancock County very few villages have public supplies. The following, however, use surface water: Bucksport, Northeast Harbor, Ellsworth, Sullivan, and Sorrento. One town in the county, Castine, gets its water from wells and springs, and Southwest Harbor gets it from wells and a pond. Lamoine has a supply from springs, and Hancock Point uses an abandoned mine shaft. A deep well was sunk at Stonington some years ago for a public supply, but it was never used.

Castine.—The village of Castine is supplied by two private water systems. The larger of these is owned by Mr. A. M. Deveraux, who has several deep drilled wells situated on the summits of the hills occupying the center of the peninsula. In addition to the wells a number of springs are used.

The first well was put down by a driller who promised water at a depth of 60 feet. The well was drilled 57 feet 8 inches, and the tools stuck, making it necessary to abandon the hole. It was filled with stones to prevent any other driller from making use of it, and a second hole was drilled 2 feet away. This one went 62½ feet, got a good supply of water, and continued 3 feet deeper for a reservoir. A third hole, 12½ feet distant, was drilled to a depth of 70 feet. By pumping the two successful wells it was found that they communicated and that it was only necessary to put a pump in one of them. The water level stands 25 feet from the surface. Another well was drilled 10 feet away from No. 3, to a depth of 80 feet, water being found at the same depth, 62½ feet, and rising to the same level as in the others, 25 feet from the surface. Later, hole No. 2 was deepened to 110 feet.

On another hilltop a well 675 feet in depth was drilled for the same water company. This is an 8-inch well and is one of the deepest in Maine. The first water was found at 425 feet, and filled the well within 27 feet of the surface. The cost was $3,500, and much trouble was caused by losing the drill, obtaining a crooked hole, etc., due to inexperienced drilling. The well is reported to yield about 13 gallons of water a minute through the day, but is not very satisfactory on account of its poor construction.

The three principal wells belonging to this system are now pumped by a windmill into a cement-lined tank situated on the hilltop near by. The maximum capacity of the three wells is reported to be about 27 gallons a minute. The capacity of the tank is more than 25,000 gallons, but the supply from the wells is seldom sufficient to fill it. The other well belonging to the system is situated about a mile from these and is also pumped by a windmill into a tank having a capacity of more than 30,000 gallons. The supply from this well also is insufficient, and the tank is never full.

As a temporary supply, to make up the deficiency of water in the wells, the owner has installed a system of springs. These are situated on low land in the eastern part of the peninsula, in sand and gravel. A system of tiling several hundred feet in length was put in, extending 6 to 10 feet from the surface downward into the clay on which the sand rests. This system catches the water held in the sand by the impervious clay below and is reported to give 10,000 to 20,000 gallons of water a day. The water is pumped by steam to a reservoir or tank near by, and thence to a reservoir on the hill near the deepest well.

Mr. Deveraux reports that 150 water takers are on his system. This includes two hotels, one of which recently put down a drilled well for the purpose of obtaining its own supply. Unfortunately this well was a failure. With the wells and springs constituting the public supply there seems to be plenty of water to meet the demand for it. The spring system, however, is reported to be only temporary, and the owner contemplates installing a system of driven wells instead. Mr. Deveraux's company is sometimes known as the Castine Water Company.

The other company in Castine is known as the Castine Aqueduct Company. The water is taken from springs in gravel, and is used by a few persons. A number of people in the village prefer the use of dug wells, as of old. Many of these wells are in poor locations and unsafe. They should be abandoned.

The price charged for water in Castine by the Castine Water Company has recently been raised from $7.50 to $10 a year. On account of this increase many people have given up the public supply and are depending on the dug wells. The price charged by the Castine Aqueduct Company to its patrons in the lower part of the town is $6 a faucet.

Southwest Harbor. The village of Southwest Harbor has a water supply taken from two sources, both owned by the Southwest Harbor Water Company. Until recently most of the water was taken from two drilled wells situated on the summit of the hill just west of the village. These wells and the conditions of water in them are described on page 141. The first well used was 136 feet deep and pumped 45 gallons a minute. The second, 20 or 30 feet from it, was sunk to a depth of 297 feet. The windmill was first situated over the old well, and an 8-horsepower gasoline engine was also established to pump both wells. As both the windmill and the engine were insufficient to pump the two wells to their fullest capacity, a secondary water supply was installed from Long Pond. Another well, 125 feet deep, was never used.

The water from the wells and pond is pumped to a standpipe 225 feet above tide, the capacity of which is 107,000 gallons, and it can

be pumped full in seven hours of continuous pumping by means of a windmill. The pressure is reported to be 90 pounds on the main street. The length of pipe connecting the village of Southwest Harbor with Long Pond is about 2½ miles. In addition to this the company has 1 mile of pipe extending to the steamboat landing and probably half a mile in the village. All these pipes are underground. The mains extending to Long Pond are 2 inches in diameter and the rest are one-half inch. Surface pipes extend to the village of Manset and to a great many cottages in the vicinity of Southwest Harbor. A 1-inch pipe runs below the sound to Greenings Island. Five fire hydrants are reported in the village of Southwest Harbor, but there are none in the outlying villages.

The majority of the people in Southwest Harbor use the water supplied by the company. A few, however, use dug wells. There are estimated to be 150 consumers, over 50 of whom, however, are summer residents. The rates are $10 a faucet in private houses and $7 in stores. During the winter all inhabitants except those on the lines which are buried use well and spring waters. The chief reason given for having so much pipe above ground is that ledge at many places lies close to the surface and to lay pipe in it would be very expensive. The water has been analyzed and is considered of excellent quality. The amount of sickness in town seems to have decreased since the waterworks were installed.

Lamoine.—Twenty families in the village of Lamoine are supplied by the Cold Spring Water Company. The water seeps out of sand deposits, and is pumped by windmill into a reservoir.

PREDICTIONS AND RECOMMENDATIONS.

Most of the towns in Hancock County seem to appreciate the value of pure water supplies. Stonington, however, while growing rapidly, has as yet no such supply. The people of this town use dug wells and springs almost entirely, and many of these are in situations where they are sure to be polluted from surface drainage. There are no sewers in the town, and altogether conditions are insanitary. It seems important that the dug wells and springs should be abandoned as rapidly as possible and a public water supply installed. This might be obtained from any one of several sources, among which are Burntland Pond and other ponds on the south end of the island. If none of these supplies are satisfactory it seems probable that a number of wells drilled in granite at a safe distance outside the village, away from the shore, would furnish plenty of water. There is always an uncertainty whether rock wells will obtain sufficient water for a village, however, and a pond supply should be obtained if practicable. There is plenty of water in the granite of Deer Isle for ordinary domestic purposes, and even for

small manufacturing and other establishments. Individuals or companies that can afford to do so will be wise to sink wells for drinking water.

In most of the summer-resort districts of the county, especially on the islands, drilled wells are rather commonly used. Although some have been failures, there have been, on the other hand, a surprising number of successful wells drilled on islands where it would seem that the supply of water in the rocks must be small. In most localities the best method of obtaining water for cottages is by drilled wells. These should not go to a depth of more than 200 feet, as deeper drilling is generally of little avail.

A number of wells situated near the coast, and especially on the small islands, have been unsuccessful, owing to the entrance of sea water, which has ruined the wells. In certain wells fresh water has first been encountered, and by continued drilling to obtain a greater supply salt water has been struck; in others salt water has been struck first, the fresh-water seams existing at greater depths. Sometimes the water of the well is fresh, but by long-continued pumping becomes salt. In any of these cases, where both salt and fresh water veins are struck, it is possible for experienced drillers, by proper manipulation, as described on page 67, to close off the salt water and redeem the well.

KENNEBEC COUNTY.

GENERAL DESCRIPTION.

Kennebec County lies in the south-central part of Maine, on both sides of Kennebec River and directly east of Androscoggin and Franklin counties. It has a length from northeast to southwest of 50 miles and a maximum breadth from east to west of 35 miles. Its area is 880 square miles, and its population according to the census of 1900 was 59,117. The chief cities are Augusta—the state capital—with 12,379 inhabitants; Waterville, with 10,899; and Gardiner, with 5,501. The county is well provided with railroads, being crossed by a line of the Maine Central Railroad along Kennebec River and another line 5 to 15 miles west of the river, meeting the river line at Waterville. From Waterville the railroad runs northeastward to Burnham, and a branch extends north as far as Skowhegan, in Somerset County. The Somerset Railroad extends from its terminus at Oakland northward to Moosehead Lake, in Somerset and Piscataquis counties. A narrow-gage railroad—the Wiscasset, Waterville and Farmington—runs southeastward from Winslow to Wiscasset, in Lincoln County, and a branch of this railroad runs from Weeks Mills to Albion. The surface of Kennebec County is rather hilly, but is not so much so as some of the other counties in the State. The elevation ranges from sea level along Kennebec

MAP OF KENNEBEC COUNTY

Showing distribution of deep wells, important springs, and communities having public water supplies

River to more than 700 feet on some of the hills. The tide on Kennebec River penetrates as far inland as Augusta. Within the county are a great many lakes, which are mostly utilized for summer resorts. The largest body of water in the county is Great Pond, in Rome and Belgrade. Throughout the county the open well is the prevailing type, but some drilling has been done. A map of this county showing distribution of deep wells, important springs, and communities having public supplies forms Pl. XV.

UNDERGROUND WATERS.

RELATION TO ROCKS AND SURFACE DEPOSITS.

Distribution of rock types.—A large part of the county is underlain by slate. There is, however, a small patch of granite, about 5 miles in breadth, lying in the common corner of Manchester, Hallowell, and Augusta, and most of the area south of Gardiner consists of a complex of slate, schist, and gneiss, which can not be separated on any map.

Structural relation of the rocks.—Throughout nearly the entire county the slate strikes very uniformly northeast, and the dip of the strata and that of the cleavage are nearly vertical. The rock ranges from very shaly, or even fissile, to hard and dense, and in some places it is schistose.

Surface deposits.—The surface deposits of Kennebec County differ greatly in character and thickness. Along Kennebec River and up many of the side valleys there is considerable clay, which rises to elevations of more than 200 feet. In places this clay is underlain by gravels from a few inches to 50 feet or more in thickness. Elsewhere the clay is overlain by sand. On the hills the deposits are mostly till from 1 to 50 feet in thickness. In places, however, rather extensive morainal deposits are found on the hills, as in the vicinity of Augusta.

WELLS.

GENERAL DESCRIPTION.

Types of wells used.—The most common type of well in Kennebec County is the old-fashioned open well. These wells range in depth from 5 to 50 feet, and are dug in gravel or bowlder clay. They are generally successful, but often run dry in summer. The water is generally of good quality except where the wells are so situated as to become polluted.

Drilled wells.—About 35 drilled wells have been sunk in the county, ranging in depth from 30 to 560 feet, the most common depth being about 100 feet. The wells are mostly 6 inches in diameter, but three or more 8-inch wells have been sunk. In general the shallower

of the deep wells have been successful, but a greater number of water veins and consequent larger supplies are obtained by going 100 to 200 feet. It happens that the largest supply reported was obtained from a well which went down more than 300 feet. This well got 50 gallons a minute at that depth. It seems worth the expense to drill as deep as this if sufficient water is not obtained nearer the surface. The deeper supplies in the slate have not been prospected, for the reason that plenty of water is obtained at shallower depths, but it would be well to drill a few test wells when more water is needed.

Quality of water.—Where unpolluted the well waters of Kennebec County are mostly good. The total solids as reported in four analyses range from 170 to 258 parts per million, but the amount of lime is never great enough to cause serious trouble in boilers. The only two complete analyses of slate waters in this county are given in the appended table (Nos. 62 and 67), but a number of field assays and other tests have been made (Nos. 60 to 70). Analyses 243 to 254 give the composition of several commercial spring waters.

DETAILED DESCRIPTIONS.

Augusta.—The city of Augusta is supplied with plenty of water of good quality from Cobbosseecontee Pond, and there is little necessity of using well water. One well 560 feet in depth, belonging to Mr. G. P. Sanborn, has been used for supplying a greenhouse. The amount of water is not large, and the well overflowed in rainy weather, indicating that the water may come from a surface source. Wells drilled in the neighboring town of Winthrop indicate that plenty of water may also be expected in the slate areas of Augusta, and wells drilled in granite at numerous places in Hancock, Lincoln, and Washington counties indicate that water may be expected in the granite areas in this city as well.

Hallowell.—Like Augusta, Hallowell has a surface water supply and is little in need of drilled wells. The only well known to have been drilled in the village is reported to have been sunk at Johnson Brothers' shoe factory. A well was drilled in 1880 on the farm of Mr. H. G. Vaughan to a depth of 70 feet, and enough water for drinking and farm purposes was obtained.

Farmingdale.—In the town of Farmingdale a number of wells have been drilled to depths of 50 to 110 feet. The water is generally of good quality, and there is plenty for ordinary domestic purposes. Assays have been made of two well waters in this town (Nos. 60 and 61).

Gardiner.—The water supply of Gardiner is taken from Cobbosseecontee Stream, just below the bridge at the upper end of the village of Gardiner. The water is reported good, but on account of the large number of farms situated along the banks of Cobbosseecontee Stream

and its tributaries and the proximity of the pumping station to the village the supply must be considered as of questionable safety for the future.

Formerly, dug wells were abundant in the village, but they are now nearly all abandoned for the city water. Some dug wells penetrate the clay and get plenty of water which never gives out and which is cold and has an excellent taste. One 20-foot well goes through clay and gravel and rests on ledge. This well is in the heart of the city and so situated that the water probably enters the gravel bed within the limits of the populated district, yet nine families use the water. A number of similar wells were seen, some of which use chain pumps. On account of the extreme danger of pollution of dug wells situated in a thickly populated village these can not be considered safe. They are probably even more dangerous than the river water. The bed of gravel underlying the clay seems irregular in thickness, in some places reaching 15 feet and in others being entirely missing. A few wells only have given out. The solution of the water problem at Gardiner seems to lie in the abandonment of the present system and the installation of a supply from a point higher up on Cobbosseecontee Stream or its tributaries, where the water is safe.

Gardiner is situated entirely in the area of the complex consisting of alternating slate, schist, gneiss, and granite. Little well drilling has been done; but in the southern part of the town there are two drilled wells, 34 and 36 feet in depth, which are interesting as showing what should and what should not be done in the location of wells. Mr. Joseph Douglas has a well drilled to the depth of 36 feet entirely in rock. A deep-well hand pump was installed with the intention of using the water for drinking. The well stands only 15 feet from the barnyard, however, and the water is colored brown and has a bad odor, indicating the existence of open cracks in the rock extending under the barnyard, and consequent pollution of the well water. A dug well 15 feet in depth on the opposite side of the road and in a safe location is used for drinking water.

As a contrast, an example of a well-kept well is that of Mr. Charles Hopkins in the same part of the town. This well is 34 feet deep, and was drilled fifteen years ago, striking schist at 5 feet from the surface. The well is pumped by a windmill and gives an abundant supply of water. By looking down the well with a hand glass after pumping it as nearly dry as possible the water can be seen issuing from a crevice as large as a man's hand. This well has obtained more water than was found by farmers in the vicinity who have blasted in rock. The blasted wells here cost much more than Mr. Hopkins's well, and thus furnish an argument in favor of the drilled type.

Waterville.—The city of Waterville, together with other towns of the Kennebec water district, obtains its supply from China Lake.

Formerly it was obtained from Messalonskee Stream, which was badly polluted and caused a great deal of typhoid fever. At present, however, there is little need of drilled wells in the city, as the China Lake water is satisfactory. It is possible that drilled wells may have been sunk in the town, but inquiry during the investigation disclosed none. If rock water supplies are desired, they can probably be obtained by drilling at nearly any point, as few unsuccessful wells have been drilled in neighboring towns.

Winslow.—In 1899 the Hollingsworth & Whitney Company had a series of seven wells drilled 60 feet from the bank of Kennebec River and 20 feet above water level. The wells are 110 to 125 feet deep and extend along a line 90 feet in length. The water was used for cooling acid in the manufacture of paper. The wells were pumped by compressed air, thereby obtaining 200 to 300 per cent of the amount obtained by an ordinary steam pump. Now, after seven years, the wells are said to have filled with sand until they are only about 90 feet in depth. While they were used, pumping one of them would lower the rest. They are now abandoned because of insufficient supply for the purpose desired, and river water is used instead. A 67-foot well belonging to the same company is still used to supply drinking water.

On the terrace above these wells a number of persons have drilled wells to depths of 30 to 65 feet. These have met with varying degrees of success, some of them having plenty of water, while others give out in dry weather. It is probable that they would be more successful if drilled to 100 feet or deeper, as a greater number of water veins would be tapped. On the terrace between Kennebec and Sebasticook rivers there are flat areas of considerable clay which are worked in places for the manufacture of brick. In places the clay is overlain by sand, and at the village of Winslow a spring issues from the sand on top of the clay and is piped to four houses for domestic use.

A rather interesting well is that of Mr. Will Glidden, which is 30 feet in depth, drilled in slate. The water rises from the slate by artesian pressure into a dug well, from which it is pumped by a windmill. The pressure of water here is derived from a 15-foot rise in the hill 400 feet back from the well. A number of wells in Winslow have been blasted in rock. The water from one well on a hill is siphoned to a house on the hillside below. Field assays have been made of water from three wells in this town (Nos. 64–66).

Chelsea.—No drilled wells are known in Chelsea, but some wells have been driven and some bored to depths of 20 or 30 feet. The dug wells are generally of similar depths and the water is almost always of good quality. It usually issues from sand. Many farms in the town and the Maine Insane Hospital obtain supplies from springs.

Oakland.—Oakland has a public supply from Lake Messalonskee. This lake does not seem to be entirely safe from pollution, but the water is considered of very good quality. Drilled wells are unknown in the town.

Pittston.—In Pittston several drilled wells have been sunk, which range in depth from 56 to 135 feet. The water seems to be good, and is used for domestic and farm purposes. The yield is 8 to 10 gallons a minute.

Winthrop.—Winthrop is the only town in Kennebec County where drilled wells have been sunk extensively, and the almost unfailing success here is an index of the supplies which may be expected to be found by drilling elsewhere in the county. No fewer than a dozen successful wells have been drilled, mostly pumping 12 to 50 gallons of water a minute.

The principal wells in the village of Winthrop are owned by C. M. Bailey Sons & Co., H. P. Hood & Son, and Charles H. Gale. The public supply of the village comes from a spring belonging to the Winthrop Aqueduct Company, from springs and drilled wells belonging to Charles H. Gale, and from springs belonging to Levi Jones. The principal water system is that of Mr. Gale, whose wells and springs are situated on the hill directly west of the village. The wells are three in number, and are 90, 96, and 65 feet deep. They give a fair amount of good water and can not easily be pumped dry. Probably half the people of the town use this supply. These wells and the associated springs are described in detail under the heading "Public supplies" (pp. 157, 158).

The best well in Winthrop was drilled in 1906 for C. M. Bailey, Sons & Co. at their factory. This was sunk to a depth of 307½ feet. At 300 feet from the surface a supply of fine water was struck, which when tested yielded 50 gallons a minute. The pump is generally run three hours a day, but has been run eight hours continuously without exhausting the supply. The water is used for boilers, but is also excellent for drinking. The analysis is given in the table (No. 67). The well of H. P. Hood & Son was drilled in 1903 to a depth of 172 feet. It was cased with 8-inch casing to ledge, a distance of 18 feet, and 6-inch pipe was then run down to 140 feet. It is reported to yield 25 gallons of water a minute and can not be pumped dry. In these two wells the water stands about 8 feet from the surface.

At Winthrop the rock is slate; at Baileyville (Winthrop Center) it is schist, but the water seems to be just as abundant. The well of Mrs. Hannah J. Bailey, drilled 200 feet through rock, obtained 15 gallons of fine water a minute and now supplies four families and a boarding house. The water is piped to the houses from a windmill. Messrs. C. I. Bailey and J. Briggs own a well together, and the depth and quality of the water were similar to those of Mrs. Bailey's well.

The yield is reported as 30 gallons a minute. All the wells at Baileyville have been successful, and the water is of good quality and has no iron taste. The marked success of wells in this vicinity is a strong indication that similar wells can be obtained in other parts of the slate area of Kennebec County.

Other towns.—In the towns of Litchfield, Albion, and Sidney there are scattering drilled wells. In the following towns no drilled wells are known to have ever been sunk, and the supplies are obtained entirely, so far as known, from open wells: Vienna, Rome, Mount Vernon, Fayette, Belgrade, Readfield, Monmouth, West Gardiner, Manchester, Oakland, Waterville, Clinton, Benton, Unity Plantation, China, Windsor, Chelsea, and Randolph.

SPRINGS.

General statement.—Springs are very common on the hillsides of Kennebec County. They usually issue from bowlder clay or sand and at many places are used for domestic and farm supplies. In Augusta the Maine Insane Hospital draws its supplies from a spring situated back in the hills. At the village of Winthrop several small aqueduct systems take their water from springs situated on the hills west of the village. These are described under the heading "Public supplies" (pp. 157, 158). Within the limits of the county are the Forest Springs, at Litchfield; Pure Water Spring, in Waterville; and Ticonic Mineral Spring, at Winslow.

Forest Springs.—The Forest Springs Water Company was organized in 1900 for the purpose of marketing the water which comes from the Forest Springs, in the town of Litchfield, 1½ miles northeast of Litchfield Plains. The springs have been renowned for their purity for more than a hundred years and are said to have been much frequented by the aborigines.

There are three springs. The first is 450 feet from the second and about a quarter of a mile from the third. The two principal springs are situated at the base of a gentle sandy slope, not far from a small brook; the third spring is farther back in the woods. The principal spring is in reality a well 6 feet in depth. At this place were encountered the following strata, from the surface downward:

Section of drift at Forest Spring.

	Feet.
Gravel loam	2
Clay	1
Fine gravel	28
	31

The spring was curbed down 6 feet and has a sandy bottom. It is situated in the woods far from any house, and the water is of excellent quality, with no chance of pollution. The analyses of the three

springs, reported in a circular issued by the company, are given in the table (Nos. 247 to 249), recalculated according to the standard method. The company has built an up-to-date bottling plant near the springs, and the water is carefully bottled and shipped in half-gallon and quart bottles and 5-gallon carboys. The flow of the principal spring is 100 gallons an hour.

Pure Water Spring.—The Pure Water Spring is situated 1½ miles north of Waterville. The water is carbonated and sold in Waterville. The hardness is given by the owners as 41.5 parts per million.

Ticonic Mineral Spring.—About 2 miles northeast of Waterville is the Ticonic Mineral Spring, the product of which is sold in Waterville. The flow is reported as 5½ gallons a minute. The analysis of this water is given in the table (No. 253), recalculated from the figures reported by the owners.

PUBLIC SUPPLIES.

General statement.—Eleven villages in Kennebec County—Augusta, Hallowell, Farmingdale, Gardiner, Randolph, Oakland, Waterville, Benton, Belgrade, North Vasselboro, and Winslow—have public supplies drawn from surface sources. The only important underground-water supply is that of Winthrop, which uses wells and springs. Hallowell, Augusta, and Vienna are reported, however, to have small spring supplies.

Winthrop.—The village of Winthrop has no regular municipal supply. There are, however, a number of aqueduct companies, and these furnish water to a majority of the population. Most of the water is supplied by Charles H. Gale, the Winthrop Aqueduct Company, and Levi Jones. The largest system is that owned by Mr. Gale, which consists of wells and springs situated on the hillside just west of the village. The wells are about 100 feet above the village and are sunk to depths ranging from 65 to 120 feet. The springs are near by, in a swampy depression in the hillsides. The water is collected in a reservoir.

At first consideration the swampy source of the springs would seem to be an argument against the use of this water. It can be said, however, that there may be no great danger of this water being contaminated by surface drainage. One house is situated on the hillside above, but it is so far away as probably to have no effect on the water supply. From the reservoir the water is piped to the town in galvanized-iron pipes, which are badly rusted by the water. As the system is a gravity system the water has a good pressure. There are reported to be about 150 patrons of the system, and this probably represents about half the village population. The wells are pumped by windmills. The owner reports that when the wells are used there is plenty of water to supply all needs. Without the

wells, however, the amount is not sufficient. No analyses of the water have been made except a sanitary analysis made some years ago.

An interesting feature was brought out in connection with this analysis. The water was sent to a chemist by a resident of the town, as it was supposed to be polluted. At the same time a sample taken from a dug well in the village was sent—a well extensively used by the residents and believed to be excellent. On receipt of the returns it was found that the water of the dug well was badly polluted and that the public supply was of excellent quality. This is a strong argument against the use of dug wells in a thickly settled village and in favor of the installation of deep-well supplies wherever practicable. There is some question in this case about the use of the springs. They are certainly not as good as the drilled wells, but they are probably safe.

The other water systems have their source in springs situated on surrounding hillsides, but the number of takers is smaller. The supply belonging to Levi Jones issues from a bowlder-clay hillside and is conveyed by gravity in galvanized-iron pipes to the village. About 35 families are reported to use the water, which is believed to be of good quality.

The water rates in Winthrop are $6 a year. The fire hydrants are supplied from an entirely separate source, pumped by the Winthrop Mill Company from another well.

Vienna.—A few persons, probably fewer than a dozen, in Vienna village are supplied by water from a large spring piped through a main three-fourths of a mile in length.

Hallowell.—In the town of Hallowell there is a supply owned by the city, reported to be derived from springs on Winthrop Hill. The water is obtained by direct pressure, and the pressure is 40 to 110 pounds. About 120,000 gallons are consumed daily.

PREDICTIONS AND RECOMMENDATIONS.

In Kennebec County few failures in well drilling have been recorded. The underlying rock of the county consists almost entirely of slate, and the almost uniform success of wells in rock of this type is contrasted to the frequent failures of wells in some other regions. So far as known, the public water supplies are at present all of good quality, although in the past there has been some trouble from water taken from Messalonskee Stream in the vicinity of Waterville. This supply is no longer used. No public supplies are known to be of poor quality. In Oakland and Gardiner, however, it would seem that the supplies are only temporarily safe; they are so situated that they may in time become polluted unless proper precautions are taken. Drilled wells in these towns would be a safeguard in case the condition of the water should cause trouble.

KNOX COUNTY.

GENERAL DESCRIPTION.

Knox County occupies a nearly central position on the Maine coast. Its length from north to south, including the outer islands, is 35 miles, and its breadth is about 20 miles. It has an area of 327 square miles, being, with the exception of Sagadahoc, the smallest county in Maine. Its population, according to the census of 1900, was 30,406. Rockland, the chief city, contained 8,150 persons, Camden had 2,825, and Thomaston 2,688. The only railroads in the county are a branch of the Maine Central which crosses from Warren to Rockland, and the Georges Valley Railroad, a short line running from Warren to Union. The surface of the county is gently undulating in the southern part, but rather mountainous in the northern part. The altitude ranges from sea level to more than 1,450 feet, the highest elevation being in the town of Camden; and its surface is covered with a considerable number of ponds and small lakes. A map of Knox County showing the distribution of deep wells, important springs, and communities having public supplies forms Pl. XVI.

UNDERGROUND WATERS.

RELATION TO ROCKS AND SURFACE DEPOSITS.

Distribution of rock types.—The rocks of Knox County consist largely of a complex of granite, diorite, slate, schist, etc. In the southeastern part of the county, extending from Rockport southwestward across Rockland, Thomaston, and Warren, are small bands of limestone rock, from a few hundred feet to about a mile in breadth, bordered by slates, schists, and quartzites. The limestone strata are much contorted, the rock is very hard, white to blue and gray in color, and is extensively quarried. In the eastern part of South Thomaston and St. George and covering the adjacent islands is a small granite area. The continuation of this area covers the greater part of Vinalhaven. A small area in the northern part of the same island and the entire island of North Haven consist of trap, slates, and acidic volcanic rocks.

The detailed geology of considerable portions of the county has been worked out by E. S. Bastin, of the United States Geological Survey, and will be given later under the names of the various towns.

Surface deposits.—The surface deposits of Knox County are irregular in thickness. Along the coast and in the lowlands the sands and clays locally run up to 100 feet in thickness, though usually much thinner, and their upper surfaces form flat plains near the coast and in the larger valleys. In the vicinity of Thomaston the clays are rather extensive. In some parts of the county there are small morainic deposits, which are in places as much as 100 feet thick, consist-

ing of sand, gravel, and till. Over the greater part of the uplands the surface is bowlder clay, ranging from 1 to 10 feet in thickness. In places this is absent and the hills consist of bare rock. Most of the water from dug wells in Knox County is derived from the surface deposits.

WELLS.

GENERAL DESCRIPTION.

Types of wells used.—The wells of Knox County are mostly dug wells, but on the coast and islands a considerable number of drilled wells have been sunk. The dug wells range from 5 to 30 feet in depth and are mostly sunk in bowlder clay or gravel. They contain plenty of water in the wet season, but in summer they often run dry.

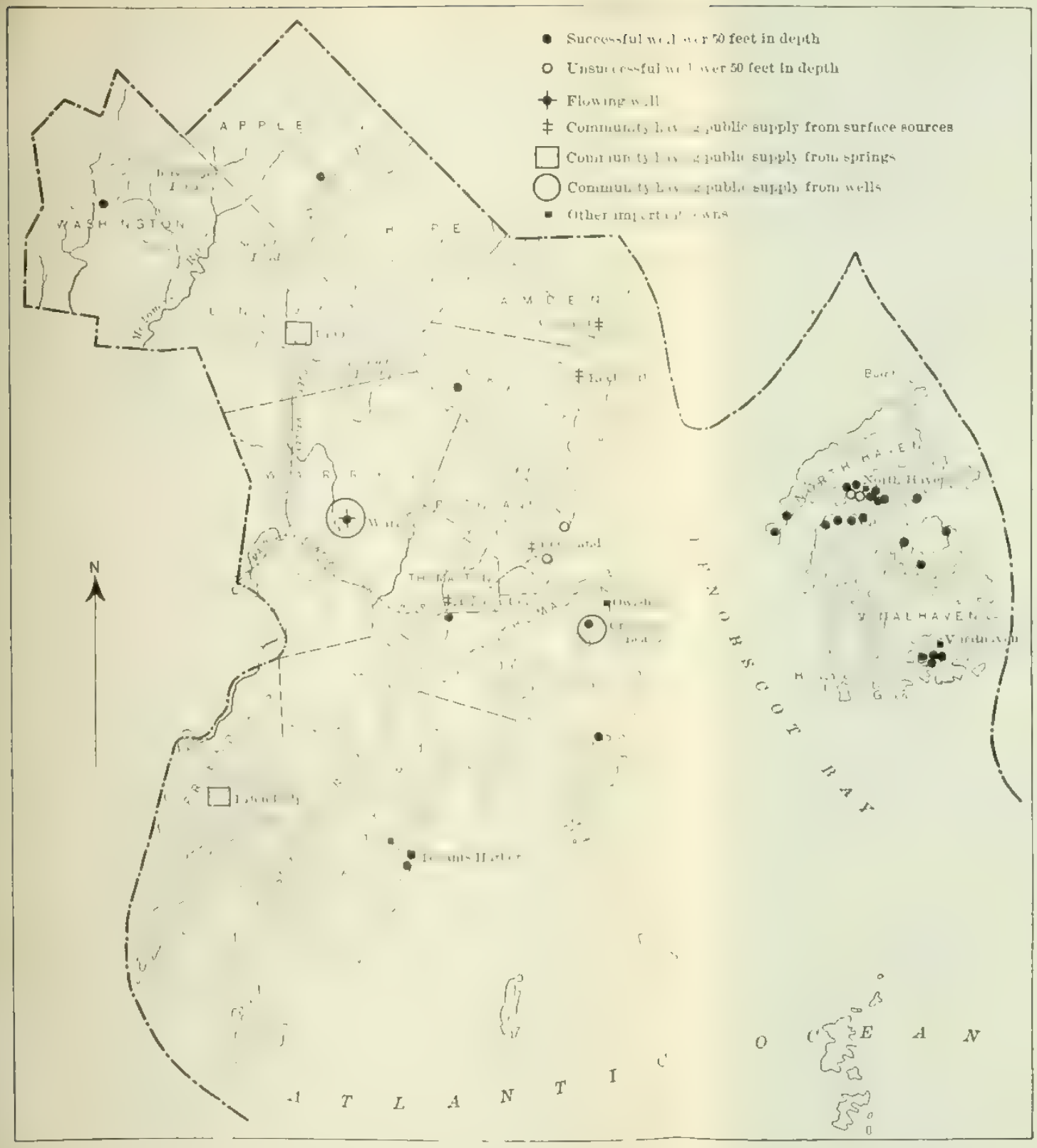
Drilled wells.—The drilled wells in this county are about 40 in number. They are from 50 to 640 feet in depth, and the yield ranges up to 25 gallons a minute. Most of the wells in the county have been successful, but several have failed. At North Haven a 300-foot well was dry, while a 200-foot well near it contained a small quantity of water. In the vicinity of Rockland one well was abandoned because the water was not sufficient to supply a large hotel, and a second well was salty. The county contains one flowing well which supplies the town of Warren. The wells between 100 and 200 feet in depth obtain the largest amount of water. Of the seven wells sunk below 200 feet, only one got an appreciable increase in the supply. These rocks probably do not contain much water below that depth.

Quality of water.—The quality of water in the wells of Knox County ranges from very soft to very hard, the hardness being dependent on the amount of lime in the rocks in which the wells are sunk. The only analysis of water from solid limestone is that of a sample from the bottom of one of the Rockland limestone quarries (No. 255). It will be noticed that neither the total solids nor the calcium is as high as in some waters from rocks that do not contain as much lime. The magnesium, however, is very high—22 parts per million.

The only other complete analyses of Knox County waters are those made from two trap wells at North Haven. The total solids in these wells are 90 and 2,057 parts per million. The excessive amount in the latter well is due to an admixture of sea water.

DETAILED DESCRIPTIONS.

Rockland.—The Rockland region is occupied largely by slate, schist, and limestone with minor areas of quartzite. In the northwest corner of the town the slates are broken up and are intruded by granites, gneisses, and similar rocks. West of the city proper is a narrow belt of crystalline limestone extending in an easterly direction from Thomaston toward Chickawaukie Pond. It is bordered



MAP OF KNOX COUNTY

Showing distribution of deep wells, important springs, and communities having public water supplies

on the southeast by a number of smaller limestone bands. This limestone is extensively quarried, some of the quarries being several hundred feet deep. Those which are abandoned are filled with water. Associated with this limestone are a few narrow bands of quartzite.

Few dug wells remain in Rockland, but along the limestone region are a number which are dug to rock, striking it at depths of 15 to 20 feet. The water here is uniformly hard. There is plenty of it in winter, but it gives out in summer. In dug wells in the immediate vicinity of the quarries the water gave out, owing to the drainage of the surface deposits by the quarrying operations.

The limestone quarries in the vicinity of Rockland, Thomaston, and Warren are the only quarries in this kind of rock in Maine, and as they throw some light on the occurrence of water in limestone, they deserve special consideration. In Rockland several quarries extend to a depth of more than 300 feet below the surface. Some of them are now abandoned and filled with water within a few feet of the surface. Where they are being worked water can be seen entering from the joint cracks below a depth of about 80 feet from the surface. An example of the amount of water entering these quarries per day is furnished by a quarry 300 feet long, 70 feet wide, and 180 feet deep. In the bottom of this quarry is a hole 25 by 30 feet across and 4 feet deep which fills in about twelve hours during the night. This is at the rate of about 10 gallons a minute. The water is pumped out in about an hour and a half in the morning. It can be seen dripping into the quarry along the joint cracks, and in one or two places springs of considerable size are found. The most water enters along the ends of the quarries parallel with the stratification of the rock, but much of it comes in on the horizontal joints.

A number of quarries show caves in limestone, due to the solution of this rock by the water. One or two caves of considerable size were found. (See Pl. VII, *B*.) The largest are 5 feet across and extend more than 5 feet inward from the side of the quarry. In one place where the drift has been stripped from the surface a former water channel about 2 feet in diameter was seen running downward into the rock. A few solution channels are seen following the horizontal joints, and in places these are 2 to 4 inches in diameter. The occurrence of water in solution channels in limestone is a common feature in such rocks throughout the country, and the drillers frequently find that the drill drops several feet when a vein of water is struck. There is plenty of water in this rock at Rockland, but it is very hard.

The city of Rockland has an excellent supply of water from Oyster River Pond, with Chickawaukie Pond as an auxiliary supply. Not more than three wells are known to have been drilled in Rockland, and these have been abandoned. One was drilled on Crockett Point

in 1900 to a depth of 22 feet, striking rock at 3 feet from the surface, but was abandoned because the water was salty. In 1906 an 8-inch well was drilled at Hotel Samoset, Rockland Breakwater. The surface was clay rising a few feet above tide, but rock was struck at 14 feet and the well was sunk to a depth of 640 feet. At 185 feet 10 to 12 gallons of water a minute was struck, but below that no water was found. This supply was not sufficient for a large hotel and the well was plugged. However, the water would have been enough for several private families. No information can be obtained regarding the other well at Rockland.

Thomaston.—Northwest of a line drawn from the western edge of Thomaston village to Mount Battux in Rockland the rocks of this town consist of slate and schist. There is also a small area of slate crossing the village of Thomaston. The most conspicuous rock east of the slate area is a band of limestone, more than a mile in breadth, extending from the southern border of the town northeastward to Chickawaukie Pond, in Rockland. South of this limestone area are a number of alternating bands of quartzite, schist, and limestone which are too complicated for description. In a limestone quarry is a spring which is reported to give a good flow of water. As in Rockland, the dug wells overlying the limestone are from 10 to 20 feet in depth, and the water is very hard. Some of the wells rest on ledge. They sometimes run dry in summer.

Only one drilled well has been sunk in the town—that of the Thomaston Brick Company. It was drilled 46 feet through marine clay, then in limestone for 340 feet, making a total depth of 386 feet. The water is hard and the supply is only about 3 to 5 gallons a minute.

South Thomaston.—The eastern and southern parts of South Thomaston are composed mostly of granite and much associated gneiss and basic rocks. Between Weskeag River and Rockland Harbor is a band of slate and schist more than half a mile broad. West of this band the area consists of the same succession of quartzite, limestone, and slate which is found in the southeast corner of Thomaston. Most of the wells in this town are dug. At Crescent Beach a well was drilled in 1906 for Mr. F. M. Smith to supply cottages at that place. The depth was 75 feet, and the well furnished 5 or 6 gallons of water a minute, which was reported to rise within 2 or 3 feet of the surface in the wet season. The well can be pumped down 30 or 40 feet, but can not be exhausted. Other data regarding it are given in the section on "Public supplies" (p. 167).

Several wells are reported to have been drilled at Owlshead and Hendrickson Point, but information regarding them has not been received.

St. George.—The town of St. George consists almost entirely of granite. There are, however, in the western half of the town con-

siderable areas of diorite. The wells of this town are for the most part dug wells, but on Harts Neck, south of Tenants Harbor, at least three drilled wells have been sunk to supply summer cottages. Those of Mr. William S. Richardson and Mr. J. B. Aldrich are rather interesting. While these wells are situated so near the houses that windmills could not be built over them, the windmills were built a few feet distant and the wells are pumped by means of a connecting rotating horizontal rod. The wells are drilled 67 and 54 feet deep, in a very hard gneissic rock. The Richardson well is reported to yield only 2 gallons of water a minute. Another well near by was also successful. At Port Clyde a well is reported to have been drilled, but no information regarding it is at hand.

Warren.—The town of Warren is almost entirely underlain by granites, gneisses, diorites, and schists, mixed in the form of a complex. There are, however, small areas of other rocks. One of these extends as a narrow strip from the southern border of the town in the vicinity of Thomaston northward along the Thomaston and Rockland line beyond the head of Oyster River. Northwest of Warren village is a small area of limestone which is quarried. Most houses in the village of Warren have dug wells, but these are abandoned and the people use the public supply. This comes from a deep drilled well situated on the high hill east of the village. It is 196 feet deep and is reported to flow 5 feet above the surface without pumping. The volume is reported to be 8 gallons a minute, and in a test the well pumped 100 gallons a minute for five days continuously. The country rock is complex, and as no rock shows within half a mile it can not be said certainly from what material the water comes. For full information regarding this system of waterworks see page 166.

Rockport.—The entire western part of Rockport, including all the area lying west of the village of West Rockport, is occupied by a complex of granite, gneiss, diorite, schist, and other rocks. The area east of this line is composed almost entirely of schist, with some slate. There are, however, a few small areas—one in the vicinity of Oakland Park, a second just south of Rockport village, a third crossing the village itself, and a fourth between Rockport village and Simonton Corners—which consist of quartzite, and smaller areas in the village of Rockport and north of Simonton Corners consist of limestone. Rockport draws its water from Oyster River Pond, and hence wells might be considered unnecessary in the village. As the rock is near the surface, however, and it is hard to pipe the streets, many dug wells are still used. They should be abandoned as rapidly as practicable. Through the country the wells are mostly dug. One drilled well of moderate depth and fair success has been sunk for Mr. Oscar Gould near West Rockport.

North Haven.—North Haven and the outlying islands included within the town are composed principally of basic lavas or greenstone. A small area in the vicinity of North Haven village, however, stretching eastward across Stimpson, Babbage, Calderwood, and Burnt islands and Indian Point, is formed of volcanic rock. On the main island of North Haven considerable drilling has been done, especially near North Haven village. Messrs. C. S. Staples and J. M. Howe put down two wells in 1902 to depths of 200 and 300 feet. The deeper well was dry and the other obtained only 1½ quarts of water a minute at 68 feet. Eighteen pounds of dynamite were exploded at that depth and the supply of water increased to 3 quarts a minute, but no more than this could be obtained. In 1893 Mr. Nelson Mullin had a well drilled 121 feet in trap in the same village. The water is called a little irony, but the supply is 5 gallons a minute and is considered satisfactory for a hotel and five cottages which are supplied from it. (See field assay, analysis No. 132.) Mr. F. S. Mead also drilled in trap and obtained 10 gallons a minute. The well belonging to Mr. F. H. Smith is 118 feet deep and supplies a store, three dwellings, a fish market, and a livery stable.

On the point a mile east of the village Dr. C. G. Wells had three wells drilled in 1891, 1895, and 1903 to depths of 122, 142, and 282 feet, getting 2, 20, and 6 gallons of water a minute, respectively. The water is found at various depths, is pumped by windmills and a hot-air engine, and is used for supplying cottages and a steam yacht. A short distance north of the wells belonging to Doctor Wells is one belonging to Mr. William A. Gaston, 57 feet in depth. One well at North Haven was ruined by the accidental admission of calcium carbide into it from an acetylene-gas generator. Analyses of two wells drilled in trap at North Haven are given in the table (Nos. 155 and 156). One of these was salty.

Vinalhaven.—The major portion of Vinalhaven is composed of granite. In the vicinity of Barley Hill and Coombs Hill and at several places near Vinalhaven village there are small areas of diorite. Zeke Point is made up of lava, but the northern half of Calderwood Neck is schist. The part of the island northwest of Seal Cove and Long Cove is largely lava, but a number of patches of diorite lie along the coast, and there are several small areas of schist and lava.

On the main island of Vinalhaven six or more wells have been drilled to depths ranging from 120 to 225 feet. Four of them are situated at the village of Vinalhaven, where sometimes as much as 20 gallons of water a minute is obtained from granite. The well of the Bodwell Granite Company, 125 feet in depth, is pumped by a gasoline engine and the water is used in dressing granite. Some veins of salt water were encountered below a depth of 50 feet in this well. The well of the Vinalhaven Fish Company, 225 feet in depth, is

pumped in the same way, gives 20 gallons of water a minute, and is used to supply a canning factory.

At the north end of the island the rock is mostly trap. There are a number of wells here, and these are from 100 to 200 feet in depth, obtaining from 10 to 25 gallons of water a minute by windmills. The well of Mr. J. M. Howe here supplies four cottages, and that of Rev. G. A. Strong supplies three cottages. (See field assay, analysis No. 133.) Mr. Howe owns several wells on the island.

The conditions observed in the granite quarries at Vinalhaven are as follows: No seepage of water from the joints was noticed, but they are somewhat stained by iron. One east-west joint, due largely to weathering, is 4 inches wide. Both systems of joints are well developed in places. In some parts of the quarries they are only 1 to 4 feet apart, but elsewhere they may be 10 or 20 feet apart. Near the bottom of a neighboring quarry four small seepages were seen from horizontal joint cracks. All the water obtained from these cracks is used for engines in the quarry and polishing house.

On Widow Island a 109-foot well drilled in granite for the Maine Insane Hospital yields 2 gallons of water a minute. The well is pumped by a gasoline engine and the water is used for domestic purposes by 70 persons. It is considered of excellent quality.

Camden.—About half the town of Camden, including the entire area lying west of a line drawn from Melvin Heights northeast to the Waldo County line, is composed of a complex of granite, gneiss, diorite, and schist. The region east of this line is occupied by slate and schist, with the exception of an area extending from the extreme west end of the village of Camden northeastward to the saddle between Mount Battie and Mount Megunticook, which is composed of quartzite, and of a small patch south of the village and extending into Rockport which is composed of limestone. There are also a few small patches of quartzite, limestone, and other rocks scattered promiscuously through the town.

Camden has a good surface water supply from Mirror Lake, and the village is not in need of wells. On its borders and in the country districts people still use dug wells, which give water of variable quality. No drilled wells are known to have been sunk.

Other towns.—In the towns of Washington, Hope, Union, Friendship, and Cushing no drilled wells are known. The conditions are as usual in the country districts and supplies can be obtained by dug wells, but these are of variable quality and sometimes run dry in the summer.

SPRINGS.

Knox County is well provided with springs. In the town of Camden Mr. Frank Alexander has a spring consisting of a well-like hole, 2 feet in depth, dug in the bottom of the cellar, 6 feet below the sur-

face of the ground. The material is hard "pin gravel." Mr. Alexander has a waste pipe 2 feet below the cellar and the spring overflows to a near-by valley. This spring was installed before the town had a public supply. It is described here as an example, for the reason that spring waters coming from under dwelling houses are not safe. When springs have their origin in sands and gravels at a distance from houses they are generally preferable, but they can not be recommended when they are so situated as to be influenced by surface drainage from surrounding buildings.

PUBLIC SUPPLIES.

General statement.—The towns of Rockland, Camden, Rockport, and Thomaston have an excellent public water supply furnished by the Camden and Rockland Water Company and drawn from Mirror Lake, in the town of Camden. Two communities in this county—Warren and Crescent Beach—use deep wells for their public supplies, and two villages—Union and Friendship—have spring supplies.

Warren.—The village of Warren is supplied by the Warren Water Company, which has an artesian well situated on the hillside about one-half mile east of the village. The well is 196 feet in depth and is a drilled well 6 inches in diameter. It was sunk 54 feet in 1900 and to its present depth in 1903. The flow began at 165 feet and increased to 185 feet. The well is reported to flow 5 feet above the surface without pumping and to give a volume of 12 to 15 gallons a minute, but is fitted with a windmill and a gasoline engine for use when necessary. When tested for five days and five nights it averaged 100 gallons a minute. The hill on which the well is situated consists of a gentle bowlder-clay slope rising toward the east, and the well is about 100 feet above the highest part of the village. The water is pumped to a reservoir situated some 800 feet distant. It is in the midst of pasture land, but is surrounded by a barbed-wire fence 10 feet from the nearest point of the reservoir. The pressure is 85 pounds. An 8-inch main carries the water to 10 fire hydrants and most of the residences in town.

This water company is said to have been formerly conducted by Mr. White, who had a shallower well on the same site as the present one. On account of failure the present company was formed. The well seems to give a plentiful supply of water, as evinced by one occasion when there was a fire and two lines of hose were run to the burning building without the water being exhausted. The rate is $7 a year for family use for one faucet, but an extra charge is made for other faucets. The water is said to be of excellent quality. The principal constituents shown by a field assay are given in analysis No. 134.

Crescent Beach.—Crescent Beach, in the town of South Thomaston, is supplied by a drilled well belonging to Mr. F. M. Smith. The well is situated on a gentle gneissic slope at some distance from the village. It is 75 feet deep and was guaranteed by the drillers to give 6 gallons a minute. It is pumped by a windmill which has been run steadily a week at a time. Sometimes a gasoline engine is used. The water can not be pumped out, but can be lowered 30 feet. When not pumped it often stands only 2 feet below the surface. The water has been considered good by the users, but sometimes gives a bad odor. An examination of the well disclosed the probable cause. The casing is open at the surface, thus giving a chance for mice, snakes, or other small animals to fall in. This is a good example of how a well should not be kept. The top of the casing should always be closed. The well has supplied about 25 cottages at the beach, also the stable and hotel buildings.

Union.—The village of Union is supplied by the Union Water Company through a gravity system from springs on the hillside east of the village. There are two springs, reported to flow 2 gallons a minute each, which seep out of bowlder clay. About 80 families are said to use this water. The pressure is 50 to 80 pounds.

Friendship.—The village of Friendship is supplied by a spring system owned by the Friendship Water Company, of Warren. The water boils up through sand at a reported rate of 20 gallons a minute. It is pumped into a tank by a windmill. It is good soft water and seems to be entirely satisfactory for domestic use. The system is said to supply 60 families.

PREDICTIONS AND RECOMMENDATIONS.

The public water supplies of the larger villages of Knox County are all of good quality, so far as known, and there seems to be little necessity for their improvement. In view of the fact that most wells drilled within the county have been successful, it is suggested that drilled wells be used more extensively. They will be found especially satisfactory on the islands and rocky coasts of summer resorts, where it is difficult to get an adequate supply from open wells.

LINCOLN COUNTY.

GENERAL DESCRIPTION.

Lincoln County lies a little southwest of the center of the Maine coast. It is 40 miles in length from north to south and 20 miles from east to west. Its area is 520 square miles, and its population in 1900 was 19,669. Wiscasset, the county seat and largest town, contained only 1,273 inhabitants. About 7 miles of the western border of the county fronts on Kennebec River. The county is crossed by the

Maine Central Railroad from Wiscasset to Waldoboro and by the Wiscasset, Waterville and Farmington Railroad, a narrow-gage line running north from Wiscasset to Winslow in Kennebec County. The surface of the county is much broken up by indentations from the sea projecting many miles inland, and the coast is lined by a great many islands. The altitude ranges from sea level up to about 500 feet on a few of the hills. Along the coast considerable well drilling has been done. The distribution of deep wells, important springs, and communities having public supplies is shown in Pl. XVII.

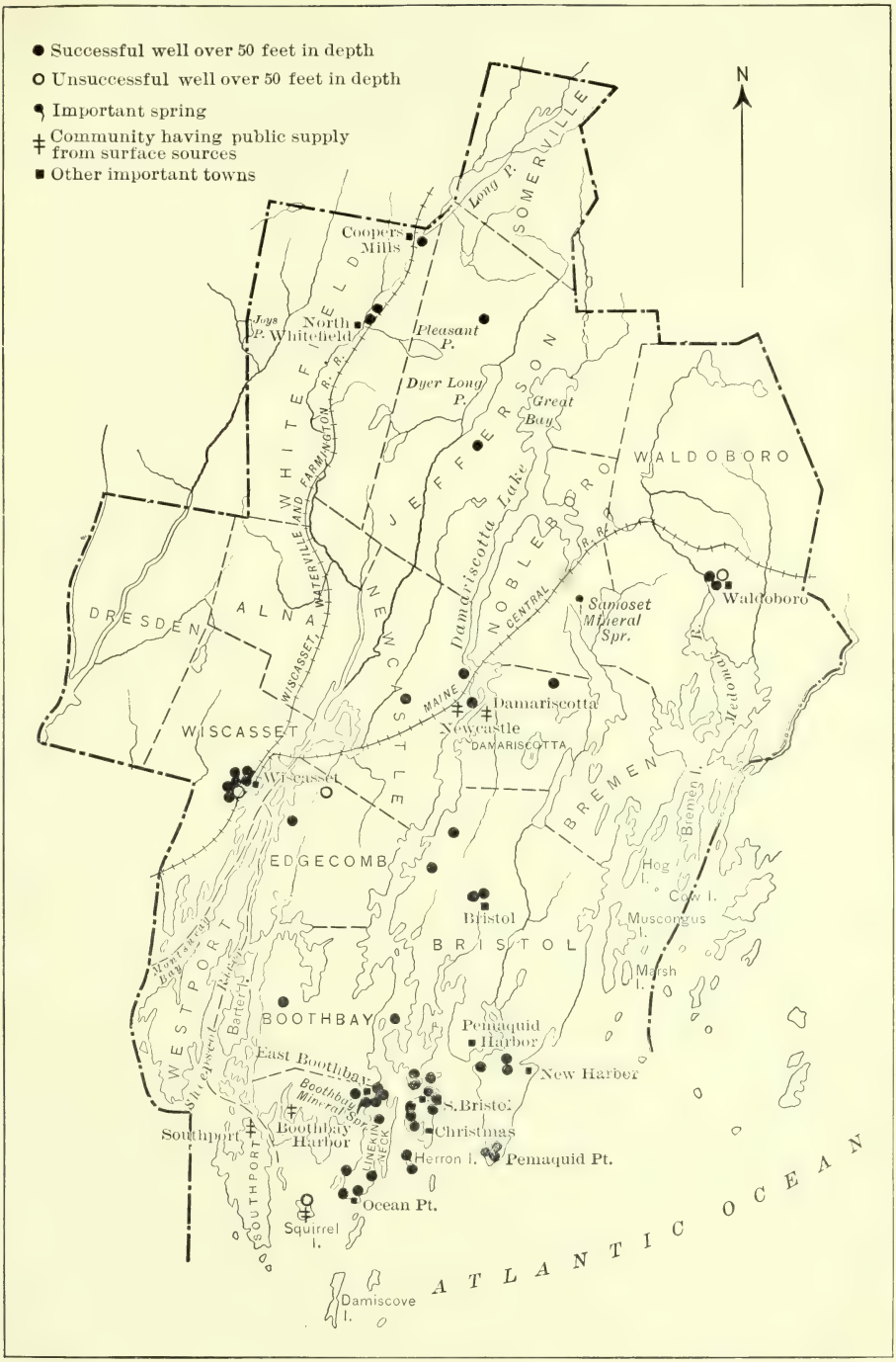
UNDERGROUND WATERS.

RELATION TO ROCKS AND SURFACE DEPOSITS.

Distribution of rock types.—Nearly the entire area of Lincoln County is composed of a complex of slate, schist, gneiss, pegmatite, etc. The greater part of the towns of Waldoboro and Bremen is, however, occupied by granite. Smaller granite areas exist within the limits of the complex, but they are for the most part not large enough to be mapped.

Character of rocks.—The rock complex of which most of Lincoln County is composed is similar to the areas of complex in other counties. Where outcrops are seen they may consist of dense schist, striking in a northeast-southwest direction and having a nearly vertical dip, or of granite or gneiss or pegmatite. In most places the exposures consist of a mixture of these types, perhaps with gradations between them. Here and there these rocks are intruded by masses of trap, diorite, or other igneous rocks. There are no quarries in the area of complex in this county or elsewhere in the State, and for that reason the actual conditions in which the water is held in the rocks are not well known. A few railroad cuts show water seeping out of horizontal joint cracks or along the contact between various types of rock. In some sections along the railroad the water is seen in cracks which have been opened by blasting. This would seem to indicate the desirability of "shooting" wells where no water is obtained. In general the occurrence of water in the area of complex is likely to be less abundant than in areas of granite or of slate. This is presumably due to the fact that the changes in character of the rock interfere with the circulation of water through definite joint cracks extending for long distances.

Surface deposits.—The surface deposits of this county are as a rule not of great thickness. The coasts are rocky, and the islands contain only a few feet of drift. Some exposures of clay are found along the valleys, and these may be expected in protected areas anywhere up to an elevation of 200 feet or so. Small areas of stratified sand and gravel also rise to the same altitude. Most of the uplands



MAP OF LINCOLN COUNTY.

Showing distribution of deep wells, important springs, and communities having public water supplies.

of the county are covered by till, which varies in thickness from 1 to 20 feet or more. The thickest deposits of drift are probably in the vicinity of Waldoboro, where there are large moraines.

WELLS.

GENERAL DESCRIPTION.

The wells of Lincoln County consist of both dug and drilled types, the former being by far the most numerous, as in other regions. There are, however, more than 80 drilled wells within the limits of the county. These range in depth from 30 to 360 feet, and the usual size is 6 inches. The most common depth of wells in this region is somewhat less than 100 feet, and probably not more than 70 feet. There are, however, a few wells as much as 150 feet deep and three wells have been sunk more than 200 feet. In general the deeper wells are not so successful as those of moderate depth. The 360-foot well on Ocean Point is an exception to this rule, and in that well a large portion of the water was obtained near the bottom.

The quality of the water from deep wells in Lincoln County should probably be ranked lower than that of any other county in Maine. The most common defect is the large proportion of iron which it contains. This is shown in few analyses; it is in reality but a few parts per million, but is sufficient to give a distinct mineral taste to the water and sometimes makes the water too rusty to be used for washing. The mineral matter ranges from 95 to 419 parts per million, as shown by analyses Nos. 135 to 149 and 22 to 28 in the table. The water is generally called hard by the residents. Analyses of three mineral springs are given also (Nos. 256 to 258). No flowing wells are known within the limits of the county.

DETAILED DESCRIPTIONS.

Wiscasset.—As Wiscasset has not yet a public water supply, a considerable number of drilled wells have been sunk in the village. More than fifteen years ago a well was drilled for Mr. W. G. Hubbard at the Hilton House to a depth of 70 feet. At 68 feet a fine supply of water was struck, which can not be exhausted when pumped at the rate of 35 strokes a minute, and after eight or ten hours' pumping the well contains just as much water. It is supposed to yield about 15 gallons a minute. When first struck the water would fill the well at the rate of 15 feet in five minutes. It can be lowered 50 feet by pumping. A gasoline engine was installed and a well house and tank were built at a total cost of about $1,000.

Another good well was drilled in 1905 at the custom-house to a depth of 75 feet, and water was struck at 72 feet, increasing in volume near the bottom of the well. It supplies the custom-house and half a dozen families for drinking and cooking purposes. This well was

cased 6 feet into rock, and at the surface of the ground a cement floor was put in as a preventive of contamination by infiltration of surface drainage. The water can be lowered, but it will return to its former level in ten minutes. Four hours' pumping will not exhaust it.

In the 48-foot well of Mr. S. B. Cromwell, at Wiscasset, the drill dropped 3 or 4 inches when water was struck, indicating the occurrence of joint cracks. Several wells between 30 and 50 feet in depth in this village have good supplies. Most of them can not be pumped dry. The water sometimes has a bad taste, which is believed to be due to its action on the galvanized-iron pipe, but may be due to the iron naturally contained in the water.

Two wells in Wiscasset, both situated at the Turner Center Creamery, only a block from tide water on Sheepscot River and 5 feet above tide, have been spoiled by the entrance of salt water. One of them, 64 feet in depth, was drilled in 1890 for Mr. John Budd, who had a gristmill on the spot. After being used a couple of years the water became too brackish for use. A second well was drilled at the creamery to a depth of 103 feet. This is too brackish for drinking, but is used for cooling cream.

A well drilled for Mr. A. R. Smith is an example of a correct method of construction where rock lies near the surface. In this well the depth to rock is 6 feet. The surface materials were dug out and the casing was driven 3 feet into the rock and cemented firmly to the ledge, thus preventing all entrance of surface drainage.

The deepest well at Wiscasset is 154 feet deep, sunk at the county jail. This is another example of good construction. Rock reaches the surface here, and a pipe was put in and the rock coated with cement for several feet around the pipe. A laboratory analysis of the water from this well is given in the table (No. 149). Field assays of three other wells are also given (Nos. 146 to 148).

In brief, well drilling in Wiscasset seems to have met with marked success. Most of the families in town use dug wells, which give plenty of water the year round and have never seriously interfered with the public health. Many of these wells are in poor situations, however, and as the use of dug wells is always dangerous in a village, they should be abandoned and a public water system established without delay. Meanwhile drilled wells are highly recommended.

Edgecombe.—At South Newcastle, in 1901, Mrs. C. A. McMichael drilled a well 56 feet in depth. Water struck at that depth rose to within 1½ feet of the surface, but the supply was small and the well was abandoned. No other drilled wells are known in town.

Newcastle.—The villages of Newcastle and Damariscotta are supplied with water by the Twin Village Water Company, obtaining its supply from Little Pond. The water seems to be of good quality. Throughout the town of Newcastle dug wells prevail, but several

drilled wells have been sunk. The two Glidden wells, 85 and 88½ feet in depth, struck water near the bottom and obtain 7 gallons a minute. They are pumped by a hot-air engine for domestic use. At Damariscotta Mills a well was drilled 64 feet deep for Mr. S. W. Waltz, and plenty of water was found for all ordinary purposes. An analysis of this water is given in the appended table (No. 24).

Damariscotta.—Damariscotta is situated just across the river from Newcastle, and the two villages have a joint supply from Little Pond. The supply seems to be good, and no wells have been drilled in the village. In the northeastern part of town a well was sunk for Mrs. S. G. Chapman to a depth of 87½ feet, and the principal water supply was obtained at 57 feet. The amount is said not to be large, but there is plenty for two houses and two barns, and it is reported to have increased during the course of years. A field assay is appended (No. 23). The water is said to become softer every year. The well is fitted up with a model type of windmill and tank, and the water runs by direct pressure to the house.

Bristol.—The town of Bristol covers a large area, and many drilled wells have been sunk within its borders. At Bristol Mills most people use dug wells and obtain fair supplies of water. A few persons have springs, one of which supplies three families. Wells have been drilled here for Dr. J. W. P. Goudy and Mr. J. C. Hyson, 52 and 62½ feet deep, respectively. Doctor Goudy's well obtains a plentiful supply of good water (analysis No. 22). It is pumped by a force pump situated inside the house, although the well is 10 feet away. There is a tank in the top of the house, and the owner has installed all modern improvements. The water at Bristol Mills is reported to be much better in quality than that at South Bristol.

In the northwestern part of the town Rev. H. E. Cotton has a well 72 feet in depth, but he obtained only about 1 gallon a minute.

At Pemaquid a well was drilled in 1901 for Mr. C. A. Sprowl to a depth of 45 feet. The principal water was struck at 30 feet, but it has a poor taste. The same trouble was experienced with the well of Mr. M. B. Macdonald. At this place nearly every house has a cistern. The well water is poor and very irony. On Pemaquid Point Mr. W. A. Elliott had a well drilled in 1901 to a depth of 51 feet, getting a good supply of water at that depth. The well supplies the hotel and probably 90 people during the summer. Two complete analyses of well waters from Pemaquid Point are given in the table (Nos. 145 and 145a). An analysis of water from granite at Pemaquid Beach is given also (No. 25).

At New Harbor there are several wells, 30 to 140 feet deep. The water is highly charged with mineral matter, has a bad taste, and is very destructive to the well casings. Mr. E. W. Fossett drilled a well 33 feet deep and put in galvanized-iron pipe. The water was

not fit to drink, and he changed to block-tin pipe. The water ate pinholes through this pipe, and it was necessary to resort to a wooden pipe. The water is still very irony, showing that the mineral taste did not come entirely from the casing.

At South Bristol several wells have been drilled, the water in most of which is very irony. In the well at Mr. N. W. Gammage's hotel rather bad conditions were encountered, and they are described for the reason that they have an important bearing on the purity of water in deep wells in general. At a depth of 2 feet from the surface a small slanting crack was encountered, which reaches the surface 5 feet from the well. The surface of the rock here was thoroughly covered by cement, but afterwards grass and worms were found in the well water, and an analysis by the State board of health showed a large amount of organic matter. It is supposed that these must have entered through an extension of the crack or through an intersecting crack on the other side of the well. On account of the poor quality of the water the well was temporarily abandoned for cistern water. In this well a small quantity of water was found at 30 feet, but the largest volume was encountered at 100 feet. The well was drilled 3 feet deeper to furnish a reservoir.

The largest group of wells in Bristol is found at Christmas Cove, on the south end of Rutherford Island. Here there are 13 drilled wells, ranging from 25 to 125 feet in depth. Several of these have an abundant supply of water and have never been pumped dry. One of the largest wells in Lincoln County is that of Mr. W. E. Little. The others range from 1 to 3 gallons a minute. The water is mostly of good quality, but rather hard, and some of it is a little irony. Two laboratory analyses are given in the table (Nos. 135 and 136). The well drilled for Mr. W. E. Little at the Christmas Cove House was sunk to a depth of 106 feet, rock lying about 22 feet from the surface. The water was obtained at 50 feet, but it was not sufficient in quantity, so the next year the hole was deepened and 2 gallons a minute were obtained. Most of the wells at Christmas Cove are ordinary open wells, some of which are blasted in rock.

On Heron Island, just off the point of Christmas Cove, are two wells, one of which, belonging to Mr. William C. Damon, is 115 feet deep. It can be pumped dry, but furnishes plenty of water for the use of a single cottage. A complete analysis of water from this well is given in the table (No. 142). On the north end of the island a well was drilled for the Heron Island Company to a depth of 162½ feet, and got plenty of water in wet weather, but not enough in a dry spell. This well is used to supply the hotel near by. It stands in a small depression in the surrounding rock, and the top of the casing is open, with nothing to prevent the entrance of dirt, stones, or small animals. (See p. 66.)

Boothbay Harbor.—The villages of Boothbay Harbor and Bayville are supplied by an excellent water system owned by the town and obtained from Adams Pond. No drilled wells are known to have been sunk in the town, but if it should become necessary to use well water it is probable that drilled wells would be successful so far as the quantity of water is concerned. As indicated by the conditions in neighboring towns, the water would probably be found to be somewhat irony.

Boothbay.—Most of the wells in the town of Boothbay have been drilled at East Boothbay. The Hodgton Brothers' well is 120 feet deep, but got most of the water at 47 feet from the surface. By looking down the well with a hand mirror water can be seen issuing from fissures in the rock. In quality it is called very good, and people from a number of houses use water from it. It is also used to supply a blacksmith shop here. Mr. Frank Rice, near by, has a well 75 feet in depth, which was first drilled 34 feet in 1905, but the amount of water was not sufficient, and the next year it was sunk to 75 feet, and a plentiful supply was obtained. The water has, however, a bad "vitriol-like" taste. An analysis is given in the table (No. 141). The water is sufficient to supply a dozen families. Mr. Frank Weston had a well drilled 75 feet deep, which obtained water at a depth of 65 feet from the surface. The well can not be pumped dry, but the water has the same bad taste. Capt. J. L. Race drilled only 35 feet, and his well yields plenty of water, but has the same defect. Field assays of two of these wells are given in the table (Nos. 139 and 140).

On Ocean Point three wells have been drilled, the deepest being that of Mr. L. J. Crooker. This well was first drilled only 60 feet, but the supply gave out in a dry summer; for that reason it was drilled the next year to 360 feet, and now there is plenty of water. The cylinder of this pump is down only to 120 feet, indicating that the head of the water sustains itself well. It is pumped by a gasoline engine and windmill. Most of the water is reported to come in near the bottom of the well. An analysis is given in the table (No. 144).

The well of Mr. John A. Royal, situated 1 mile northeast of Ocean Point, is 90 or 100 feet in depth and obtains its principal water supply at 85 feet. It is pumped by a hot-air engine and can not be exhausted. The owner has installed a 600-gallon tank and has all modern improvements in his house. On Lincoln Neck, about 1 mile east of East Boothbay, is a well belonging to Miss F. C. Lowden. This is about 250 feet in depth and obtains 10 gallons of water a minute, supplying two cottages. Two wells near together, 154 and 157 feet deep, situated near East Boothbay, were formerly used for manufacturing purposes, but were abandoned. The supply is variously reported as 3 to 27 gallons a minute, but the water was highly charged with mineral.

To summarize the conditions in the town of Boothbay, it can be said that the water as a rule is rather poor, having a strong mineral taste, which is probably for the most part iron, but which may come in certain wells from the zinc in the galvanized-iron casing dissolved by the water. In locations where the taste is not objectionable it will be advisable to sink wells, as the quantity of water is in general sufficient for ordinary purposes.

Southport.—The only drilled well known in the town of Southport was sunk on Squirrel Island for the hotel. It was drilled to a depth of 200 feet in granite, obtaining one-half gallon of water a minute at 40 feet from the surface. The supply was insufficient for the hotel, and the well has never been used. Water mains are now laid across the bay from Spruce Point, and the Boothbay Harbor supply is used for the hotel and cottages.

Waldoboro.—Two wells in the village of Waldoboro, belonging to Mr. R. L. Benner and Miss E. F. Genthner, are 56 and 88½ feet deep, respectively, in granite. The supply is about 5 gallons a minute in each, obtained from a depth of 48 and 84 feet, and the water is of excellent quality. Miss Genthner's well had a good supply of water at 30 feet, and the water level rose within 7 feet of the well mouth. On drilling 20 feet deeper, however, another crevice was struck, and the water level dropped 8 feet. The marked contrast in the quality of water here to that at East Boothbay and Bristol shows the superiority of water in granite to that in the region of complex. A laboratory analysis was made of one of these waters (No. 28) and a field assay of the other (No. 27). Mr. Benner has the pipe of his well cemented to ledge.

In 1904 a company was chartered in Waldoboro to sink a well for public supply on top of the moraine-like gravel hill east of the village. The well reached a depth of 200 feet, of which 176 feet were in rock, and yielded 10 gallons of water a minute. The funds of the company then gave out and the well was never completed. Most of the people in Waldoboro use dug wells, many of which give water of poor quality. The town is in great need of a public supply. Wells similar to the one drilled by the old company might be put down and a satisfactory supply obtained. The citizens have become discouraged in regard to well drilling, however, and are suspicious of putting money into any new scheme. It is possible that a satisfactory supply could be obtained from Storer Pond or some other pond at a distance from the village.

Whitefield.—At Coopers Mills, in the northeast corner of Whitefield, three wells have been drilled to depths of 46, 65, and 28 feet. In the well of Mr. S. E. Hopkins water was found near the surface and drilling was stopped. This well can be pumped dry in twenty minutes, but will fill again rapidly. The water is excellent for drink-

ing, but contains a little iron. A field assay is given in the table (No. 138). The wells of Mr. Charles H. Ashford and Mr. Newell Avery obtained sufficient water for domestic purposes, but the iron taste is noticeable; consequently Mr. Ashford uses his water only for drinking. A laboratory analysis was made of this water (No. 137).

At North Whitefield at least three wells have been sunk, that of Dr. A. R. G. Smith reaching 114 feet. All the wells here are of good quality except for the slight taste of iron.

Jefferson.—In the northwestern part of Jefferson Mr. Abram Brann had a well drilled to a depth of 91 feet, obtaining water at 25 feet from the surface, which is excellent for drinking, but a little irony. At Bunker Hill a well belonging to Mr. L. R. Hodgkins was drilled to a depth of 119 feet. This water also contains iron.

Other towns.—In the town of Alna at least one drilled well has been sunk, but no information regarding it could be obtained. In Somerville, Nobleboro, Bremen, and Dresden no drilled wells are known, and the conditions are such as are ordinarily found through the country districts. It is probable that supplies in these towns will be of similar quality to those found in other sections. On the island of Monhegan, situated several miles from the mainland, drilled wells are not known, but it would seem desirable to sink them, as supplies of fresh water could probably be obtained.

SPRINGS.

General statement.—Springs are fairly abundant in Lincoln County and are used by a number of farmers for private supplies. They can generally be obtained on steep hillsides, and most of them issue from deposits of bowlder clay. There are no commercial mineral springs within the limits of the county, but reports have been received of two springs which are of some interest.

Boothbay Medicinal Spring.—At East Boothbay is a spring which is rather interesting, as the water is chalybeate, containing 20 parts per million of iron. The total solids amount to 212, and the constituents are given in the table (No. 256), recalculated from the owner's report of the analysis. The flow of this spring is reported to be 2½ gallons a minute. The water is sometimes carbonated.

Samoset Mineral Spring.—The Samoset Mineral Spring is situated one-half mile east of Nobleboro. The water is interesting, in view of the fact that it contains 425 parts per million of total solids—more than any other spring in Maine of which the water has been analyzed. (See analysis No. 258.) Of this, sodium constitutes 127 parts. As the chlorine is low, it is possible that there is considerable sodium carbonate in this water. This spring also contains 19 parts of iron, making it highly chalybeate. The flow is reported to be 2½ gallons a minute. The water is carbonated.

PUBLIC SUPPLIES.

The towns of Lincoln County are so small that few have public supplies. The villages of Newcastle and Damariscotta have united to obtain a supply, brought from Little Pond by the Twin Village Water Company. Boothbay Harbor and Bayville have a supply from Adams Pond, and this is also piped under the bay to Southport and Squirrel Island. The town of Waldoboro once attempted to obtain a supply for the village by sinking a deep well, but there was financial trouble and the company was dissolved. Wiscasset has no public supply, but is greatly in need of one. Conditions in these towns are described under the various town headings.

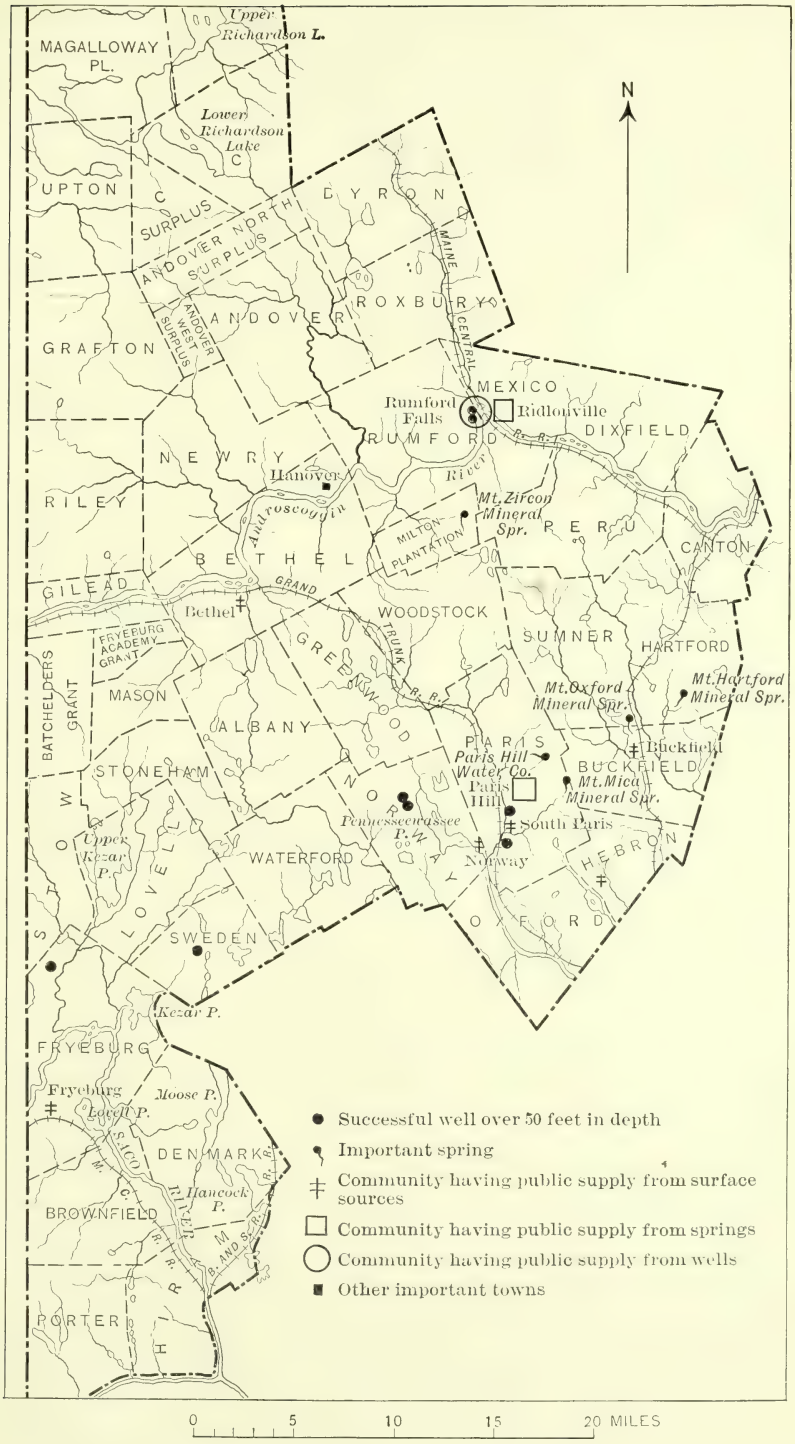
PREDICTIONS AND RECOMMENDATIONS.

The villages of Lincoln County are so small that public supplies are less necessary than in some other counties. However, as already noted, Wiscasset and Waldoboro should install water systems as soon as practicable. As explained above, the supplies are poorer in this county than in any other part of Maine. This is due principally to the fact that the water comes from an area of complex in which the rocks are very irony, and it is inevitable that some of this iron content should be dissolved by the water. There are, however, within the complex area small patches of granite, ranging from a few feet up to several miles in extent. It has been found that water in these patches is excellent, in marked contrast to that in the areas of mixed rocks. Hence the principal recommendation to make for Lincoln County is that whenever possible a well be sunk in granite in preference to shale, schist, or any other metamorphic rock. The waters from granite have been found by analyses to be of high quality.

SOUTHERN OXFORD COUNTY.

GENERAL DESCRIPTION.

Oxford County is situated in western Maine, bordering on the New Hampshire line; it is bounded on the north by Canada, on the south by York County, and on the east by Franklin, Androscoggin, and Cumberland counties. Its length from north to south is 110 miles, and its extreme breadth is about 40 miles. The area of the county is 1,981 square miles, and the population according to the census of 1900 was 32,238. Rumford Falls is the largest town, containing 2,595 inhabitants. This county is very hilly and in parts it is very mountainous. The elevation of the surface ranges from 300 feet on Saco River and 350 feet on Androscoggin River to 3,125 feet at the summit of Mount East Royce. Androscoggin River crosses the county from west to east near its center, and this river has its source in the same county farther north. Saco River crosses the southwest corner of the county. A large number of



MAP OF SOUTHERN OXFORD COUNTY.

Showing distribution of deep wells, important springs, and communities having public water supplies.

lakes and ponds are scattered throughout the area, but the largest are situated near its north end. Welokennebacook and Molechunkamunk lakes lie entirely within the county, and Umbagog and Mooselookmeguntic are largely included within its limits.

The county is comparatively well served by transportation lines. The Grand Trunk Railway crosses it in a general northwesterly direction from Lewiston in Androscoggin County to Androscoggin River on the boundary between Oxford County and the State of New Hampshire. The Maine Central Railroad crosses the southwest corner of the county, along Saco River from Fryeburg to Hiram. The Portland and Rumford Falls Railway extends northward from Mechanic Falls in Androscoggin County to Canton on Androscoggin River; it follows this river northwestward to Rumford Falls, and then extends northward into the wilderness. A small portion of the north end of the county, lying entirely in the wild lands, is outside the area considered in this report.

The deep wells, important springs, and communities having public supplies are represented in Pl. XVIII.

UNDERGROUND WATERS.

RELATION TO ROCKS AND SURFACE DEPOSITS.

Distribution of rock types.—The rocks of Oxford County fall naturally into two groups. In the first group belong the granites and associated gneisses and schists of the complex; in the second group belong the slates. West of a line drawn from a point near North Fryeburg northwestward to Locke Mills, and northward beyond Roxbury on the Portland and Rumford Falls Railway, the area is mostly a mixture of slate, granite, gneiss, etc., with the exception of a solid granite area entering from the vicinity of Rangeley Lakes and extending southward to the vicinity of Grafton, and one or two smaller granite areas. Southeast of the above-mentioned line the rocks are largely granite. They include, however, areas of gneisses, schists, and possibly other rocks which can not be differentiated on the map and which have not been studied in detail.

Structure and relations of rocks.—These rocks are similar to those of Androscoggin County. The granite is of diverse character, ranging from a very coarse grained typical granite to a fine-grained rock which is more in the nature of aplite. These rocks are cut by beds of gneiss and schist, and here and there mineral springs issue along the contact. Pegmatite, a very coarse grained granitic rock, which in places contains rare minerals, is abundant in Oxford County, but is found only in small bodies. This is the type of rock occurring at Mount Mica, in the town of Paris. The characteristics of the slate of Oxford County have not been studied.

Surface deposits.—The surface deposits of Oxford County consist largely of bowlder clay, which ranges in thickness from a few inches on many rugged hills to more than 50 feet in other places. There are large deposits of gravel in the county, but, as might be expected, these occur mostly along the valleys. Clay in this county is rare. In the surface materials water is generally abundant, but is likely to give out in the dry season.

WELLS.

GENERAL DESCRIPTION.

Types of wells used.—Open wells are the most abundant type in Oxford County. These range in depth from 5 to 50 feet and are generally successful. Frequently, however, the supply of water is not sufficient in a dry season and it is necessary to resort to springs. In some parts of the county, where the surface deposits are soft enough, driven wells have been sunk a few feet, and many of these are successful.

Drilled wells.—Drilled wells are not abundant, and so far as known only about a dozen have been sunk within the limits of the county. Most of them are in Norway, Rumford Falls, and South Paris, but there are several in other towns. The most common size is 6 inches, but one 8-inch and one 12-inch well were reported. The depth ranges from 50 to 125 feet. Generally these wells have been successful in obtaining plenty of water for ordinary domestic use. Three of them, however—one in Rumford Falls, a second in South Paris, and a third in Sweden—are not used on account of insufficient supply. One of these three was the deepest well in the county. The wells are used mostly for domestic purposes, but at South Paris one well has been sunk to supply a factory with drinking water. The supplies are obtained mostly by hand pumps or windmills.

Quality of water.—One well was abandoned on account of a strong taste in the water, presumably coming from the galvanized-iron pipe used for casing. Otherwise the quality of water from the wells of Oxford County is as good as the average. Few analyses of Oxford County well water have been made. The most important, which were of water from driven wells at Rumford Falls, will be found in the table (Nos. 187 to 189) and are discussed on pages 183–185. Waters from several of the springs of Oxford County have been analyzed and the compositions are given in the table (Nos. 259 to 265).

DETAILED DESCRIPTIONS.

Rumford.—The village of Rumford Falls has a fair water supply from driven wells situated on the flood plain of Androscoggin River at the upper end of the village. (See pp. 184–185 and analyses 187 to 189.) With this exception few wells are in use in the village, and

only three drilled wells were found. The wells of the public waterworks are from 20 to 35 feet in depth and are mostly in sand. The system is described in detail under the heading "Public supplies."

Dr. C. M. Bisbie once sunk a well in the upper part of the village to a depth of 73 feet. A little water was found at 25 feet from the surface, just below the top of the bed rock. The amount was considered insufficient and the well was abandoned. Other wells have been drilled, but no information regarding them could be obtained. At one time a well was started at a livery stable, but when the hole was down 6 feet the driller was required to give an expensive bond before proceeding, and this resulted in the abandonment of the work. Such requirements discourage well drilling, and it should be remembered that deep wells are a decided advantage to any community. It is probable that small amounts of water can be obtained by drilled wells in the rocks at Rumford Falls and vicinity. The upper part of the village of Rumford Falls, known as Virginia, is supplied by springs issuing from drift and piped to the houses. Mexico, across the river, is supplied by several aqueducts from springs on the hills, which supply 10 to 20 houses each.

A field assay of the water from a spring near the cataract is given in the table (No. 263). A few miles from Rumford Falls, in Milton Plantation, is the Mount Zircon Mineral Spring, described on page 182 (analysis No. 260).

Paris.—Paris Hill, the county seat of Oxford County, is supplied by springs, and wells are not much used. These springs are described on page 185 and the analyses are given in the table (No. 261). At South Paris several driven wells have been sunk. The best of these is probably the one drilled in 1906 for the Mason Manufacturing Company. It was sunk to a depth of 117 feet, 40 feet of which was drilled in sand and the rest in granite. The test showed 250 gallons of water an hour, and the quality was good. A well sunk for Mr. John H. Howland went to a depth of 122 feet in granite, but obtained little water. The well was "shot" with 90 pounds of dynamite without success. On the sand plain in the village of South Paris a number of driven wells have been sunk to depths of 10 to 30 feet. Some of these reach ledge. The wells got plenty of water and can not be exhausted. The public supply of South Paris is taken from Norway Lake and is used by a large number of people.

Buckfield.—The village of Buckfield has recently installed a good water supply, which is piped from South Paris. Formerly dug wells were extensively used in the village, but these are being abandoned, as the water is not as satisfactory for domestic purposes as the town water. Within a few miles of Buckfield, near the edge of the adjacent towns of Hartford and Sumner, are the Mount Hartford Mineral Spring and the Mount Oxford Spring, described

below and analyzed as reported in the table (Nos. 259, 259a, and 264).

Norway.—The water supply of the village of Norway, like that of Paris, is drawn from Norway Lake, and most of the people use it. A few persons use driven wells, and as the village is situated on the flat sand deposit only a few feet above the lake and river plenty of water can generally be obtained in this manner. Driven wells are better than dug wells and are advised outside the village. The desirability of their use in the village, however, is questionable, as, so far as known, the lake supply is satisfactory.

Sweden.—In the northern part of Sweden a well was once sunk to a depth of 189 feet on the farm of Mr. Walter Evans. It is reported to be drilled in "trap," and yielded 8 gallons of water a minute. As the farm is now abandoned, the well is not used, and no other information regarding it could be obtained. With this exception the wells are mostly less than 30 feet in depth and are ordinary open wells. The supplies are small, but there is enough water for farms, except in very dry weather.

Fryeburg.—In 1890 a well was sunk for Mr. L. W. Atkinson at North Fryeburg to a depth of 115 feet. There are some driven wells here, but most wells in the town are dug. Some families use cisterns to catch rain water.

Other towns.—With the exception of the towns described above, no localities in Oxford County are known to use wells of other than the ordinary open and driven types, which are mostly less than 40 feet in depth. These wells differ somewhat with the kind of material, but as a rule plenty of water can be obtained in wet weather, and smaller supplies, or none at all, in a dry spell.

SPRINGS.

General statement.—The springs of Oxford County are very numerous, occurring on steep hillsides, along the valleys, and even on gentle slopes. A great many of them are utilized by farmers for drinking. The water from others is bottled and sold in Boston and New York. The commercial mineral springs of the county are as follows:

Mount Hartford Mineral Spring, Hartford.
Mount Oxford Mineral Spring, Sumner.
Mount Zircon Spring, Milton Plantation.

Mount Hartford Mineral Spring.—The Mount Hartford Mineral Spring is situated in the southern part of the town of Hartford, about 4 miles northeast of Buckfield village, high up on the slopes of a granite hill. The spring is owned by the Mount Hartford Mineral Water Company, but is now leased for ninety-nine years to the Consolidated General Mineral Spring Company, of Philadel-

phia. The water seeps out of a bowlder-clay hillside and is caught in a granite-walled tank and piped to a bottling house lower on the hillside. The water is shipped to Philadelphia and sold as the "Mount Hartford natural mineral water." It is colorless and odorless and is said to flow more than 40 gallons a minute. A large proportion of it is carbonated and made into ginger ale.

The water is low in mineral matter, as shown by the analyses (Nos. 259 and 259a). Analysis 259 is recomputed from the analysis given in the circular issued by the company. Analysis 259a is part of the following complete analysis, which was made by W. W. Skinner, of the Bureau of Chemistry, United States Department of Agriculture, in connection with cooperative work on mineral waters conducted by the Geological Survey and the Bureau of Chemistry.

Analysis of water from Mount Hartford Mineral Spring.

[W. W. Skinner, analyst.]

Gases (cubic centimeters per 1,000 grams at 0° C. and 760 mm. pressure):	
Carbon dioxide (CO_2), free	.....
Carbon dioxide (CO_2), set free from bicarbonates on evaporating to dryness	3.80
	Parts per million by weight.
Phosphoric acid radicle (PO_4)	None.
Metaboric acid radicle (BO_2)	None.
Arsenic acid radicle (AsO_4)	None.
Silica (SiO_2)	9.00
Sulphuric acid radicle (SO_4)	1.62
Bicarbonic acid radicle (HCO_3)	20.47
Nitric acid radicle (NO_3)	.88
Nitrous acid radicle (NO_2)	None.
Chlorine (Cl)	4.00
Bromine (Br.)	None.
Iodine (I)	None.
Iron (Fe) and aluminum (Al)	Trace.
Manganese (Mn)	None.
Calcium (Ca)	4.43
Magnesium (Mg)	1.03
Potassium (K)	.76
Sodium (Na)	3.95
Lithium (Li)	None.
Ammonium (NH_4)	Trace.
Oxygen to form Fe_2O_3 and Al_2O_3	.....
	46.14
Free ammonia	Traces.
Albuminoid ammonia	Traces.
Nitrogen as nitrates	200
Nitrogen as nitrites	None.
Oxygen consumed	8.00

Mount Oxford Mineral Spring.—Mount Oxford Mineral Spring is situated in the town of Sumner, about midway between the villages of East Sumner and Buckfield, on the line of the Portland and Rumford Falls Railway. It is owned by the United Mineral Springs Company, of New York. The water issues from a steep bowlder-clay hillside, far from all sources of pollution. The hillside above is wooded. There is no color or odor, and only a slight taste. The flow is estimated as 8 gallons a minute. From the granite tank in which it is caught, and which is covered with a glass case, it is piped down the hillside to a bottling house on the railroad at Saunders Crossing, whence it is shipped. The storage tank is 40 feet below the spring and holds 4,000 gallons. Most of the water thus far (1906) is shipped to Providence, R. I., but some of it is sent to Philadelphia. The pipe used in carrying the water from the spring to the bottling house, a distance of 80 rods, is of wrought iron, this kind of pipe having been recommended by the State chemist of Massachusetts as the best for this water. The water has been analyzed and is low in mineral matter. The composition recomputed from that reported in the circular issued by the company is given in the table (No. 264).

Mount Zircon Spring.—The Mount Zircon Spring is owned by the Mount Zircon Spring Company, of Boston. It is situated in the eastern part of Milton Plantation, high up on the western slope of Mount Zircon. It seeps out of bowlder clay on a gentle, wooded hillside, somewhat higher than the only house in the vicinity. The water has no color, odor, or taste, and is reported to flow 14 gallons a minute. It is bottled on the spot and shipped to the city. A 5-gallon carboy of it retails in Boston for $1.50. This is a very old spring, and is said to have been a popular resort long before the Poland Spring was known. There was formerly a large hotel here, which was well patronized until it was burned. The spring is inclosed in a small house, in which is a glass-covered porcelain-lined tank with a sand bottom, out of which the water bubbles. This water contains 33 parts per million of mineral matter, as shown in the analysis (No. 260), which was recalculated from the analysis reported in the circular issued by the company.

Cataract Spring.—On the west side of the cataract at Rumford Falls is an excellent spring, issuing from a flat crevice one-fourth inch in size in a pegmatite ledge, about 2 feet below the surface. The spring is situated just below the highway, above which the hill rises very steeply. The country rock is a complex. This spring is owned by the Rumford Falls Power Company, which does not use it, but many of the inhabitants haul the water for drinking, preferring it to the city water. The flow is about 3 gallons a minute. The highest temperature at the point of emergence in August was 45½°.

The spring is surrounded with granite curbing 10 feet across, cemented to the rock, and a small house protects it. The only analysis available is a field assay given in the table (No. 263).

Mount Mica Mineral Spring.—The Mount Mica Mineral Spring is situated on the southern slope of Mount Mica, near the boundary between the towns of Paris and Buckfield. The water bubbles out of sandy bowlder clay at an estimated rate of 1 or 2 gallons a minute. It has no color, odor, or taste. It is not sold, but people frequently carry it away in bottles for their own use. The water is reported to have been analyzed, but the analysis has not been received by the Survey. A field assay is given in the table (No. 262).

"*Magnesia Spring,*" *Buckfield.*—In the western part of Buckfield there is a spring which is reported to contain a large amount of magnesia. The water is not sold, but is carried away in bottles by a number of residents in the vicinity and is said to have medicinal properties. It is reported to have been analyzed, but no analysis has been obtained by the Geological Survey.

Jones's Spring.—About one-half mile west of Norway is Jones's Spring, the water of which is sold in Norway. The flow is small, being reported as only one-half gallon a minute.

PUBLIC SUPPLIES.

General statement.—The towns of Buckfield, Bethel, Fryeburg, Hebron, South Paris, and Norway have public supplies taken from surface sources. Paris Hill and the little town of Ridlonville use springs situated much higher up on a neighboring hillside, and Rumford Falls has a system of driven wells. The underground supplies will be described in detail.

Rumford Falls.—The water supply of Rumford Falls was formerly taken from Androscoggin River, but two years ago a system of 2½-inch driven wells was sunk at the upper end of the village, below the settlement known as Virginia. The wells are 68 in number and range from 22 to 35 feet in depth. They are about 30 feet apart, in sand and gravel that form the plain bordering the river, and are situated along a line 300 feet from the river. The system is owned by the Rumford Falls Water and Light Company. From the pumping station the water is pumped to a standpipe on the hill, with a capacity of 500,000 gallons and an elevation above the surface of 75 feet. The water is carried in cast-iron pipes and distributed by gravity from the standpipe. There are said to be 440 connections, which include most of the houses in town. Water to the amount of 1,164 gallons a minute can be pumped by the present plant, and this rate is continued twenty-four hours a day. There seems to be an abundant supply of water and as yet there has been no trouble about obtaining it.

The principal problem connected with the supply is its quality. Androscoggin River, situated close by, is of course polluted by drainage from the mills and towns farther up the stream. In addition to this factor, there is a swampy depression situated 50 feet east of the eastern line of the wells, and this depression lies downhill from the village of Virginia, in which the drainage conditions are poor. The water has a "mucky taste" and sometimes a little color in summer, and these defects have been supposed by residents of the city to be due to this depression.

An interesting case connected with this supply was reported by the manager of the water company. The inhabitants of the village objected to the water from time to time for the reason that it was supposed to be contaminated. In 1905 a series of samples were collected and submitted for analysis to Prof. F. C. Robinson, of Bowdoin College. The results of these analyses are given in the table (Nos. 187 to 189), in which sample 1 was taken from the pumping station, sample 2 from the end of a long galvanized-iron main, and sample 3 from Hotel Rumford. These analyses show that the total solids are rather low. In sample 2 there were 20 parts per million more than in 1 or 3. The chlorine, silica, calcium carbonate, sulphates of sodium and potassium, and sodium chloride are the same or very nearly so in all three analyses, but the carbonate of iron differs. The one surprising discrepancy in the analyses is that the amount of carbonate of zinc reported is 1.084 parts in sample 2, which was taken from the galvanized-iron main, while samples 1 and 3 showed no zinc. It is also noticeable that the carbonate of iron is greatest in the same sample and next greatest in the sample taken from Hotel Rumford, while the iron in the water at the pumping station is small. This seems to indicate, as stated by Professor Robinson, that the water in traveling through a galvanized-iron main dissolves a considerable quantity of the zinc, owing to the carbon dioxide in the water. This gas is more often present in well water than in river or lake water and is a desirable constituent, but it seems to have a bad effect on the water by dissolving the zinc. The iron causes a deposit when the water stands. The zinc renders the water unfit for domestic use and is probably the cause of some of the taste which is reported. For this reason Professor Robinson recommended that galvanized-iron connections be taken out and connections of tin-lined or brass pipe be substituted. The brass pipe is probably the best, but is more expensive. The bacteria in the water are all harmless. As seen by the analyses, they were most numerous at the pumping station and decreased rapidly toward the points where the water was used. The results of these analyses seem to indicate strongly that the taste complained of was due to the use of galvanized-iron connections.

Another recommendation made by Professor Robinson was that the swampy depression back of the wells should be filled up, as it affords a reservoir for stagnant water, and in the future may cause pollution of the wells. This recommendation is here reiterated, and it can not be too strongly urged that the conditions in the village of Virginia be kept as sanitary as possible in order to prevent any possible contamination of the public water supply. The pipes connecting with the mains in the streets are 16 inches in diameter, but in the distant parts of town the mains are as small as 6 inches. There is 1 mile of 16-inch pipe, and in all there are about 5 miles of pipe. Black iron pipe is used at present, and it seems to give satisfaction. There is now a regulation of the company which does not allow plain iron, lead, or galvanized-iron pipe as connections. Water rates are $8 a year for ordinary faucets. The pressure on the main street is reported as 70 pounds. A test made of the pumping plant showed that 300,000 gallons of water could be pumped by it. This calls for only 25 gallons a minute from each of the 68 wells.

The strata found in the wells consist of 18 to 25 feet of fine sand at the top, below which is 10 feet of fine gravel, in which the water occurs; below this is another layer of fine sand. The water in the wells stands higher than in the river, indicating that it is not derived from that source, but comes from back in the hills.

Paris Hill.—The Paris Hill Water Company was incorporated and a gravity system of waterworks from Crocker Hill Springs was installed in 1899. The springs are situated on the side of a high hill about 2 miles east of the village. The water flows through a 2-inch cast-iron pipe to a reservoir 100 feet below the springs and 210 feet above the village. The pressure is 90 pounds. Water mains 6, 4, and 2 inches and service pipes three-fourths inch and one-half inch in size are used, and the total length of the mains is nearly 3 miles. There are no fire hydrants, but there are 70 taps, and about 350 persons, or approximately 95 per cent of the population of the village, use the public supply. It has been estimated that 5,000 to 15,000 gallons of water are used daily. The supply is sufficient for all present needs.

The Crocker Hill Springs seep out of gravel far removed from any source of pollution. The water is of as good quality as any other in Maine. Analyses made in 1901 for the owners by a New York chemist (name unknown) and recalculated by the United States Geological Survey are given in the table (No. 261). The amount of total solids—11, 13, and 14 parts per million—is extremely low. Samples 1 and 2 were taken from the reservoir and sample 3 at the residence of Mr. George M. Atwood, at Paris.

Ridlonville.—The Shaw-Ridlon Land Company, of Ridlonville, owns a water supply derived from springs. The water is used only for domestic purposes and is satisfactory, but fire protection is needed.

SOUTHERN PENOBSCOT COUNTY.

GENERAL DESCRIPTION.

Penobscot County lies somewhat east of the center of Maine and has a length of 120 miles, extending from near the head of Penobscot Bay northward into the wilderness. Its greatest breadth east and west is about 70 miles, and its area is 3,254 square miles. Only the southern portion is covered by the present report. The northern border of this area lies near Oldtown and Charleston. The population of Penobscot County according to the census of 1900 was 76,246. The largest city is Bangor, with a population of 23,500, and Oldtown comes next with 5,763 inhabitants. This county is moderately hilly. Its elevation ranges from sea level to nearly 5,000 feet on the eastern slopes of Mount Katahdin, many miles north of the area covered by this report. In the area under consideration the greatest elevation is only about 1,000 feet, in the southeast corner of the county, on the edge of the mountains. Scattered throughout the county are a great many lakes, of which the largest are Newport Pond, Pushaw Lake, and Nichols Pond. Penobscot River flows through the center of the county from north to south, and on it are situated Bangor, Oldtown, and a number of the other principal towns. The Maine Central Railroad crosses from west to east between Dover and Bangor and then runs northward along Penobscot River. This railroad has a branch running from Bangor southeastward to Ellsworth, in Hancock county, a second branch running southward along Kennebec River to Bucksport, in Hancock County, and a third extending northward from Newport to Dover, in Piscataquis County. The Bangor and Aroostook Railroad runs northward from Waldo County, and crosses the center of Penobscot County to South Lagrange, where it joins a branch of the same road which connects with the Maine Central Railroad at Oldtown. The locations of deep wells, important springs, and communities having public supplies are shown in Pl. XIX.

UNDERGROUND WATERS.

RELATION TO ROCKS AND SURFACE DEPOSITS.

Character and distribution of rocks.—Nearly the entire portion of Penobscot County included within this report is composed of slate. The only exception is a patch of granite which lies in the extreme southeast corner of the county, entering it for only a few miles in the mountain region. The slates which cover the county are typical of the class of slates which cover large areas in central Maine. They are fine grained and split parallel with the stratification, which is nearly vertical and strikes very uniformly in a direction about N. 30° E. Here and there dips of as much as 60° toward the southeast or northwest are found. In places numerous quartz veins are seen parallel with the stratifica-

- Successful well over 50 feet in depth
- Flowing well
- Important spring
- Community having public supply from surface sources
- Other important towns

0 5 10 15 20 MILES

MAP OF SOUTHERN PENOBSCOT COUNTY.

Showing distribution of deep wells, important springs, and municipalities having public water supplies.

tion, and these indicate that in past geologic ages a great deal of water has circulated in the rock. The fact that many bedding and cleavage planes are rather open near the surface indicates the possibility that a large proportion of the abundant water now found in these slates is held in these planes. Some of the water, however, occurs in joint cracks, an examination of the rock where it is quarried showing that there are abundant cracks in other directions than the cleavage planes which might hold water.

At Brewer the direction of the principal system of joints is northeast and the hade about 50° SE. A second system strikes southeast and hades about 30° SW. A road cut at this place shows considerable water seeping down along the cleavage planes. The general structure of the rock can also be well seen at a number of quarries along Kenduskeag Stream at Bangor.

Surface deposits.—The surface deposits of Penobscot County differ greatly in thickness and character. Along Penobscot River the sands and gravels are locally as much as 100 feet in thickness, and some rather extensive areas of clay extend up the side valleys for several miles. Away from the river the gravels may be as much as 50 to 100 feet thick in exceptional cases, but they generally occur in the form of eskers, morainic deposits, and irregular patches of gravel.

Underlying the sands, gravels, and clays and overlying the bed rock almost everywhere is the regular bowlder-clay deposit which is found nearly everywhere in Maine. This ranges in thickness from a foot to more than 50 feet. Along Penobscot River in the vicinity of Veazie are long sections showing nothing but bowlder clay. Some of these are as much as 60 feet in height above the river. The upper part of this section is of a buff color for about 10 feet from the surface, and below that is the ordinary hard blue bowlder clay. There are a great many bowlders in the deposits, some of them up to 3 feet in diameter. No stratification can be seen in this type of deposit.

On a hill in the southern part of Orono a well was once dug for Mr. N. W. Page to a depth of 54 feet. This well passed through nothing but hard bowlder clay and found no water until near the bottom.

WELLS.

GENERAL DESCRIPTION.

Types of wells used.—Although the old-fashioned type of dug well is very abundant in this county, as elsewhere in Maine, and far predominates in number over all other types, drilled wells are more widely scattered and are used by a larger number of people than in any other county in southern Maine. In the area under consideration there are supposed to be only two or three towns which contain no drilled wells, and in these towns there is no reason why drilled wells should not be successful.

Drilled wells.—The drilled wells which have been sunk in Penobscot County are mostly 6 inches in diameter, this being the most common size used in Maine. There are a few, however, which are reported as small as 4 and 5 inches. Several 7-inch wells have been drilled, and a well in Stetson, one of the oldest drilled wells in the State, is said to be 12 inches in diameter. A few wells are larger at the top than at the bottom, and a number are drilled in the bottom of dug wells, but this type is not recommended. The proportion of successful wells in Penobscot County is probably larger than in any other county in Maine. Altogether more than 85 wells have been drilled to depths greater than 50 feet, and it is not supposed that more than half a dozen of them have been abandoned for want of sufficient water.

Quality of water.—Only one well is known in Penobscot County with the mineral content so high that the water can not be used. A number of wells are reported, however, that have been contaminated by surface drainage and thereby rendered dangerous. As more analyses have been made of water from slate wells in Penobscot County than in any other slate area in Maine, a fair knowledge of the quality of water is available. Of 35 analyses which have been made, 8 are nearly complete laboratory analyses, the rest being field assays and tests for only a few constituents. All analyses will be found in the table (Nos. 72 to 106). As will be seen, the total solids range from 74 to 834 parts per million, depending largely on the proportions of lime, sulphates, and carbonates in the water. The highest lime recorded is 214 parts per million in the well at the Bangor House, but no other reports exceed 82 parts. Several wells report 5 to 10 parts per million of iron, but this is believed to be an error, as no iron can be tasted in these waters, and these figures should possibly be placed under "iron and alumina." Analyses of several spring waters are given in the table (Nos. 266 to 268). The waters of Penobscot County are as hard as any others in southern Maine, the hardness being in many waters from 100 to 300 parts per million.

DETAILED DESCRIPTIONS.

Bangor.—As the present water supply of Bangor is taken from Penobscot River it is badly contaminated by sewage and manufacturing wastes from Oldtown and other villages. Hence the problem of obtaining water from wells in the city is very important. Some persons still use dug wells, but the most popular type and the type advised in nearly every case is the drilled well. Within the city limits 13 drilled wells have been sunk; they range in depth from 30 to 425 feet.

The deepest well in Bangor, one of the deepest successful wells in Maine, is situated at the Eastern Maine Insane Hospital, 1 mile east of the city proper. This well was drilled in 1896 to a depth of 425 feet. A little water was struck at 50 feet, but the principal supply was

found at the very bottom of the well when all hope of success had been given up. The drill made a perceptible drop at the time the principal seam of water was struck. The water does not stand within 200 feet of the surface, but notwithstanding this fact 30 gallons a minute, the full capacity of the pump, can be obtained. Three hundred or more people are supplied for drinking and laundry purposes. Analysis No. 75 is a field assay of water from this well. When used in the laundry the water has to be softened.

Some of the best wells in Bangor were drilled during 1906 at the various schoolhouses in the city. The contract between the city and the drillers specified in every case that they must get at least 2,000 gallons of water a day. Wells are situated at the high school, the Palm street school, the Larkin street school, and the Union square school, and all have been successful in getting an inexhaustible supply of fine water. The depths vary from 72 to 217 feet, the deepest wells being generally the best. The water is not only used for drinking every day by the school children and by hundreds of passers-by, but, in the case of the high-school well at least, it has been used extensively by several hotels and numerous residences in the vicinity for their tables. On hot summer days this well is pumped almost continuously from morning till night without exhaustion. At Palm street, in a test, the well was pumped continuously ten hours a day for three days, and the water level was not affected. Careful sanitary analyses have been made of the schoolhouse wells, with the result that they were found to be perfectly safe for drinking. Mineral analyses have been made which show considerable discrepancy in certain wells, but are a good index to the character of the water beneath Bangor. (See Nos. 76–79, 86–87, and 90–91 of the table.)

Another excellent well, sunk in 1905, is that of Mr. F. L. Jones, on Center street. This well is 247½ feet deep; at this depth the drill dropped several inches and obtained water. The supply is so large that scores of neighbors use the well almost continuously. (See analysis No. 81.) The well at the court-house, which was the first well drilled in the city proper, and that of the Bangor House also furnish abundant supplies. In the latter well the drill penetrated 30 feet of clay, 15 feet of "rock," 5 feet of sand, and 240 feet of rock. As sand is very seldom found below solid rock, it is probable that the material below the clay is either an overhanging ledge or a large bowlder. The Bangor House well is said to yield 27 gallons a minute. Analyses of water from this well (No. 73) and from the court-house well (No. 88) are given in the table. Water from the well of the Maine Creamery Company is sold in Bangor under the name of Hopkins Artesian Spring water. It is believed to be excellent water. (See analysis No. 84.) The amount of total solids is only 86 parts per million, the lowest reported in analyses of Bangor wells.

One flowing well has been obtained in Bangor. This was drilled in 1906 for Morse & Co., to supply drinking water for the men at their mill. The well is situated in the valley, only a few feet from a steep, rocky hillside. The water is pumped, but will rise 2 feet above the surface without pumping. It is of excellent quality and appears to be inexhaustible. It can be pumped down 75 feet in half an hour.

The conditions in the country districts of Bangor have not been extensively investigated. Some drilled wells less than 50 feet in depth are known, and it is probable that there are some of greater depth. At any rate, conditions are very favorable for getting deep supplies.

There is a persistent belief among residents of Bangor that a limestone formation underlies the city and is encountered by certain deep wells. This is presumably due to the fact that the well waters are mostly very hard, ranging in many wells between 100 and 300 parts per million. The hardness is due in these cases, however, to the solution of small amounts of calcareous material scattered through the slates and not to any regular bed of limestone.

Brewer.—Several drilled wells have been sunk in the town of Brewer, but only two of them are deep. These were drilled in 1899 for the Eastern Manufacturing Company, at South Brewer, and reached depths of 250 and 350 feet. The water is used for cooling acid at a pulp mill. The joint supply of the two wells is reported to be only 50 gallons an hour. The wells are situated not far from Penobscot River and the 350-foot well fluctuates with the tide and is reported to yield salty water. No drilled wells more than 30 feet in depth are known in this town, but as all wells in Bangor have been successful, drilling on this side of the river is likely also to be rewarded with success.

At South Brewer a number of springs are used for supplying houses. Some of these springs are in bowlder clay, others issue from hard gravel underneath clay. One dug well in the valley of Sedgeunkedunk Stream was dug through 19 feet of clay and 3 feet of gravel, and the water rose to the surface and overflowed, thus being truly artesian. A pipe was inserted below the surface and the water carried to houses in the valley. Where good spring water can be obtained from uncontaminated sources it should by all means be used in preference to river water. Dug wells or springs in the villages are not advised, but drilled wells will obtain water which is pure and safe. Oak Grove Spring is situated in this town.

Veazie.—The people of Veazie, except those who have the public supply from Bangor, use dug wells. It is probable, however, that plenty of good water can be obtained by drilling into the underlying rocks.

Orono.—Near the southern corner of Orono a well was once dug, for Mr. N. W. Page, to the unusual depth of 54 feet. The well is situated on a round hill of bowlder clay 200 feet above the river. The material is all hard, stony bowlder clay, similar to that exposed in the section on the opposite bank of Penobscot River. On account of the tough nature of the material, it was necessary to blast with dynamite. The principal water bed was found at 30 feet, and the water seeps in everywhere lower down. The bottom of the bowlder clay was not reached. A field assay of this water is given in the table (No. 173).

The village of Orono is supplied from Penobscot River, the waterworks having been only recently installed. Several drilled wells supply moderate amounts of water from depths of 50 to 60 feet. One of these is situated at the University of Maine. It seems probable that larger supplies may be expected by sinking 100 to 200 feet deeper.

Oldtown.—Oldtown lies on the northern border of the area covered by this report, and its water supplies have not yet been investigated. No wells have been reported by correspondence, but as the rock conditions are similar to those of Bangor, where abundant and excellent supplies are found, it seems probable that like success will attend deep drilling at Oldtown.

Orrington.—Several shallow drilled wells have been sunk in the town of Orrington, getting water at about 50 feet, in slate. The best example is the well of Mr. Archie Harding, in the southern part of the town. When the well was sunk a large stream of water is reported to have gushed into it and rose 40 feet from the bottom. This well was pumped with two pumps and could not be lowered appreciably. The quality of the water is excellent. A field assay is given in the table (No. 105). Every evidence seems to favor well drilling in this town.

Hampden.—At scattering points in the town of Hampden a number of wells have been drilled, ranging in depth from 50 to 103 feet. There seems to be plenty of water for all domestic and farm purposes. In water from one of these wells a small amount of iron is reported. Four field assays (Nos. 100–103) were made in this town. In the square at Hampden Corner is a well 28 feet deep, belonging to the town. It was blasted in slate. As many as 20 families are said to use it, but it is exhausted during a drought.

Newburg.—No well reports from Newburg are at hand. The town is situated in rocks similar in nature to those at Bangor, however, and deep drilling here may be expected to be generally successful.

Hermon.—In Hermon the wells are mostly between 10 and 25 feet in depth, and they yield a fair amount and quality of water. Drilled wells are not known, but they will probably be successful if drilled deep enough.

Carmel.—In the town of Carmel a number of drilled wells have been sunk, from 45 to 75 feet in depth. The supplies are small, being generally only 2 or 3 gallons a minute, but there is generally enough water for domestic purposes. In one well it was reported irony, but otherwise it is good.

Dixmont.—At North Dixmont a number of drilled wells have been sunk, from 50 to 120 feet in depth, mostly of which yield sufficient water for domestic purposes. A single field assay was made (No. 104). In this part of the county the level of water in many shallow drilled wells varies with the season.

Etna.—A number of wells are reported in Etna from 40 to 100 feet in depth. Water is obtained at two or more levels, but the most abundant supplies occur near the bottom of the wells. In one well, 54 feet in depth, the principal seam of water was struck at 50 feet, a minor seam at 20 feet, and the yield is reported to be 15 gallons a minute. There is generally plenty of water for domestic and farm purposes. One well reports a little iron in the water.

Plymouth.—Conditions in Plymouth are similar. Well records are lacking, but it is known that water can usually be obtained in slate at depths of 50 to 100 feet. The supplies are generally sufficient for domestic and farm purposes, and the water is of good quality.

Newport.—Drilled wells are also used in Newport. They range in depth from 50 to 100 feet. Some of them are drilled in the bottoms of open wells, but this is a poor construction. (See p. 54.) The principal seams of water are encountered at all depths from 15 to 70 feet. One well, 79 feet in depth, struck the principal seam at 70 feet and a minor seam at 35 feet, and the total yield was 30 gallons a minute, but this is exceptionally large. In general there is enough water for a house and farm. Some data regarding the character of the water in East Newport are afforded by a laboratory analysis (No. 99), two partial analyses (Nos. 97 and 98), and one field assay (No. 96). The hardness and total solids are extremely high for Maine.

Stetson.—Several drilled wells have been sunk in Stetson. One of these is rather exceptional in being 12 inches in diameter. It is 74 feet deep and was sunk in 1878, getting water at the bottom. Another well, 100 feet in depth, was drilled in the bottom of a dug well and found no water. One complete analysis has been made of water from this town (No. 106).

Levant.—The wells in Levant are reported to be all dug, and the depths run from 8 to 25 feet. The quality of the water is as good as is usual in dug wells.

Glenburn.—No drilled wells are reported in Glenburn, but it is possible that one or more of them may exist. The proximity of this town to Bangor and the similarity of the slate make it probable that water of like quantity and quality will be found.

Kenduskeag.—A number of wells have been drilled in the town of Kenduskeag, and at least one of them is more than 100 feet in depth. This was sunk for Mr. Chester Weld and was dug 9 feet, blasted 13 feet, and drilled 86 feet in rock, the drilling being done in instalments, as the well repeatedly went dry. At the depth of 109 feet drilling was stopped, the supply being then 1 gallon a minute. Particulars regarding other wells in this town are not known, but it would seem probable that more water can generally be obtained by drilling deeper.

Corinna.—Drilled wells in Corinna are from 60 to 110 feet in depth. As a rule, sufficient water is obtained for domestic uses, and the quality is good. One well, however, 108 feet in depth, obtained water which was reported to be "salty," and was so poor that it could not be used. A field assay of one sample of well water is given in the table (No. 95).

About ten families in the village of Corinna are supplied by springs owned by Mr. F. F. Burrill. The supply was installed in 1897 and the water flows by gravity to the houses.

Corinth.—A few drilled wells are known in Corinth. They run from 35 to 70 feet in depth and supply plenty of water for domestic purposes. One well at East Corinth, drilled years ago, was a failure, but there is no reason why deep drilled wells should not generally be successful in this town.

Hudson.—A single well is reported in Hudson. It was drilled to a depth of 66 feet and gives enough water for ordinary domestic and farm purposes. Deep drilling in this town ought to meet with success.

Charleston.—Drilled wells in Charleston range from 16 to 190 feet in depth. Some of the shallower ones get plenty of water, but the deeper ones are the best. In this vicinity the water stands at 4 to 12 feet from the surface. Some wells can be pumped dry by continued pumping, but most of them can be lowered very little. One well, situated on the hill north of the village and 100 feet or so above the houses, was sunk for the Higgins Classical Institute to 105 feet, and the water stands 8 feet from the surface. It is siphoned down the hill to several houses in the village. There is abundant water and it can be lowered only 20 feet or so by pumping. The table includes a laboratory analysis of this water (No. 93) and field assays of the other well waters (Nos. 92 and 94).

Garland.—No information is at hand with respect to wells in Garland. The rock formation being similar, it seems probable that the conditions for obtaining water will be like those found in Charleston and that the supplies will be both abundant and good.

Dexter.—The village water supply of Dexter is taken from Dexter Pond. One drilled well is reported here 58 feet deep, but only a small amount of water was obtained. Conditions ought to be favorable for getting plenty of water by drilling 100 to 200 feet in the slate.

Other towns. In towns east of the river, with the exception of Brewer and Orrington, there are no drilled wells. For a number of miles north of the area included in this report there are scattering drilled wells, and they generally obtain plenty of water. Northeast of the area the region of abundant water supply continues into Aroostook County.

SPRINGS.

The springs of Penobscot County are fairly numerous, although not so thickly distributed as in some parts of Maine. In the vicinity of Bangor are several mineral springs which supply water for many of the inhabitants. The commercial springs of the county are as follows:

Arctic Spring, Bangor.
Chapman's Spring, Orrington.
Highland Spring, Holden Center.
Hillside Spring, Bangor.
Oak Grove Spring, Brewer.
Sparkling Spring, Orrington.

Arctic Spring.—The Arctic Spring is situated 1½ miles north of Bangor, and the water is sold in Bangor. The flow is reported as 8 gallons a minute and the temperature 44°. The hardness is 60 parts per million.

Chapman's Spring.—About one-quarter mile north of East Orrington is another spring the water of which is sold in Brewer. No information regarding it has been received.

Highland Spring.—The Highland Spring is situated on a hillside in the town of Holden, 5 miles east of Brewer. It is owned by Mr. C. B. Robinson, but is leased to Mr. A. H. Farrington. The water is said by the owners to issue from a crevice in the rock, and the spring is protected by a small house built over it. The water is bottled and shipped under the name "Highland Spring water." The analysis given in the table shows it to contain 16 parts per million of total solids. Owing to a misprint in the circular issued by the owners there are several errors in the composition reported. This water has been used in Bangor for sixteen years. The price of a 3-gallon bottle is 12 cents. This spring should not be confused with the Highland Mineral Spring in the city of Lewiston.

Oak Grove Spring.—The Oak Grove Spring is owned by Miss Jennie Farrington, of Brewer. It is situated on the eastern bank of Penobscot River, about one-half mile above the village of Brewer. The water issues from a steep slope of bowlder clay about 20 feet above the ordinary river level. In its exact geologic occurrence it issues from a bed of gravelly bowlder clay and is said to come from a vertical crack one-eighth of an inch in width in the ledge below this deposit. No houses are situated within 500 feet of the spring. The fields above

the spring are cultivated with grain, potatoes, etc. There seems to be little opportunity for pollution of the water, and it is probably perfectly safe for drinking. A small spring house has been built over the spring and the water is hauled to Bangor, where it is sold. It is colorless, odorless, and tasteless. The flow is about 1½ gallons a minute and its measured temperature is 48°. The water sells at 12 cents a 3-gallon bottle. The spring has been operated for five years by the present management, but was run several years earlier by other parties. The water is highly appreciated by the people of Bangor.

In 1906, in connection with cooperative work on mineral waters by the United States Geological Survey and the Bureau of Chemistry in the Department of Agriculture, a complete analysis of this water was made. The various constituents found are as follows:

Analysis of water from Oak Grove Spring.

[W. W. Skinner, analyst.]

Gases (cubic centimeters per 1,000 grams at 0° C. and 760 mm. pressure):	
Carbon dioxide (CO_2), free	9.00
Carbon dioxide (CO_2), set free from bicarbonates on evaporating to dryness	13.40
	Parts per million by weight.
Phosphoric acid radicle (PO_4)	None.
Metaboric acid radicle (BO_2)	None.
Arsenic acid radicle (AsO_4)	None.
Silica (SiO_2)	15.50
Sulphuric acid radicle (SO_4)	4.94
Bicarbonic acid radicle (HCO_3)	73.03
Nitric acid radicle (NO_3)	5.30
Nitrous acid radicle (NO_2)	Faint traces.
Chlorine (Cl)	5.60
Bromine (Br)	None.
Iodine (I)	None.
Iron and aluminum (Fe and Al)	.250
Manganese (Mn)	None.
Calcium (Ca)	18.58
Magnesium (Mg)	3.50
Potassium (K)	1.10
Sodium (Na)	6.95
Lithium (Li)	None.
Ammonium (NH_4)	Traces.
Oxygen to form Fe_2O_3 and Al_2O_3	.100
	135.850
Free ammonia	Traces.
Albuminoid ammonia	Traces.
Nitrogen as nitrates	1.20
Nitrogen as nitrites	Faint traces.
Oxygen consumed	4.00

A good recommendation for this water is that a Bangor photographer uses it entirely for his photographic work in preference to all other water.

Sparkling Spring, Orrington.—The Sparkling Spring is situated in the town of Orrington, about 1½ miles from the Brewer line and one-half mile east of Penobscot River. It consists of a hole dug 6 to 10 feet deep in a hollow beside a little brook flowing over a gravel terrace. The water is reported to issue from three cracks in the ledge below, and it is said by the owners that a pole can be stuck down 10 feet in one of these cracks. This statement has not been verified. The water is sold in bottles in Bangor at the rate of 12 cents a 3-gallon bottle. The analysis shows 194 parts per million of total solids, distributed as in analysis No. 268, recalculated from the company's advertisement. "There is considerable free carbon dioxide in solution." The spring is owned by Mr. Albert G. Dole and is leased by Mr. E. H. Homestead.

PUBLIC SUPPLIES.

The public water supplies of Penobscot County are taken entirely from surface sources. The city of Bangor and the villages of Brewer, Veazie, Orono, Oldtown, and Milford use water taken directly from Penobscot River. The villages of Newport and Dexter obtain water from lakes near by. There are no well or spring supplies of any consequence.

PREDICTIONS AND RECOMMENDATIONS.

The most important water question in Penobscot County arises in connection with the public supply of Bangor and several surrounding towns. These now obtain their supply entirely from Penobscot River. This water is badly polluted by sewage and manufacturing wastes from towns farther up the river, and is therefore dangerous to the public health. The people of Bangor realize this and many of them have been agitating for a safer source of supply. In 1906 the late Freeman C. Coffin, of Boston, was employed by the city council to make a thorough investigation of the Bangor water problem, for the purpose of deciding on the best source for a new supply. In his report[a] Mr. Coffin suggested four possible sources, as follows: (1) Ground-water supply; (2) Phillips Lake; (3) Felts and Eaton brooks; (4) Cold Stream Pond.

All the sources were found to be of excellent quality, but no definite decision was made between them. In regard to the ground-water supply, which was seriously discussed, two sources were considered, one in the broad flats west of Penobscot River and south of Pushaw Pond, the other east of Penobscot River and opposite the

[a] Bangor Daily Commercial, March 13, 1906.

pumping station. Either of the sources ought to yield a satisfactory supply, the chief doubt being in regard to the amount of water which can be obtained. The surface water supplies mentioned above seemed to be of equal worth, but perhaps more expensive.

It may be some time before a pure water system is installed. Meanwhile it is desirable that as many individuals and companies as can afford it should drill wells for their own private supplies. So far as known, there have been no failures in deep wells within the city, and the deeper such wells are drilled the better and larger the supplies seem to have become. For that reason it is advised that well drilling be continued at least until the supply shows signs of diminution. Elsewhere in southern Penobscot County the conditions are very similar as regards the kind of rock, and there is no reason why wells 100 to 400 feet deep should not be just as successful as in the vicinity of Bangor.

SAGADAHOC COUNTY.

GENERAL DESCRIPTION.

Sagadahoc County is the smallest county in Maine. It is situated on the eastern border of Casco Bay and extends a few miles inland, having a length from north to south of 32 miles and an extreme width from east to west of 17 miles. Its area is only 259 square miles. The population of this county according to the census of 1900 was 20,330. Bath, the largest city, had a population of 11,527, more than one-half of the population of the county. Kennebec River flows from north to south across the center of the county and follows the eastern border for a short distance north of Bath. In Merrymeeting Bay it is joined by Androscoggin River, which separates this county from Cumberland. South of Bath, Sagadahoc County is cut up by many indentations of the sea and enlargements of the river. The altitude ranges from sea level to nearly 500 feet. The principal transportation line is the main line of the Maine Central Railroad, which extends from Brunswick along the west bank of Kennebec River, a branch of the same railroad which runs eastward beyond Bath, and a second branch which extends northwestward along the eastern border of Androscoggin River to Lewiston in Androscoggin County.

A map of Sagadahoc County showing distribution of deep wells, important springs, and communities having public supplies forms Pl. XX.

UNDERGROUND WATERS.

RELATION TO ROCKS AND SURFACE DEPOSITS.

Distribution of rock types.—The rocks of Sagadahoc County must all be grouped as complex, which consists of granites, gneisses, slates, schists, and diorites, so rapidly alternating with one another that

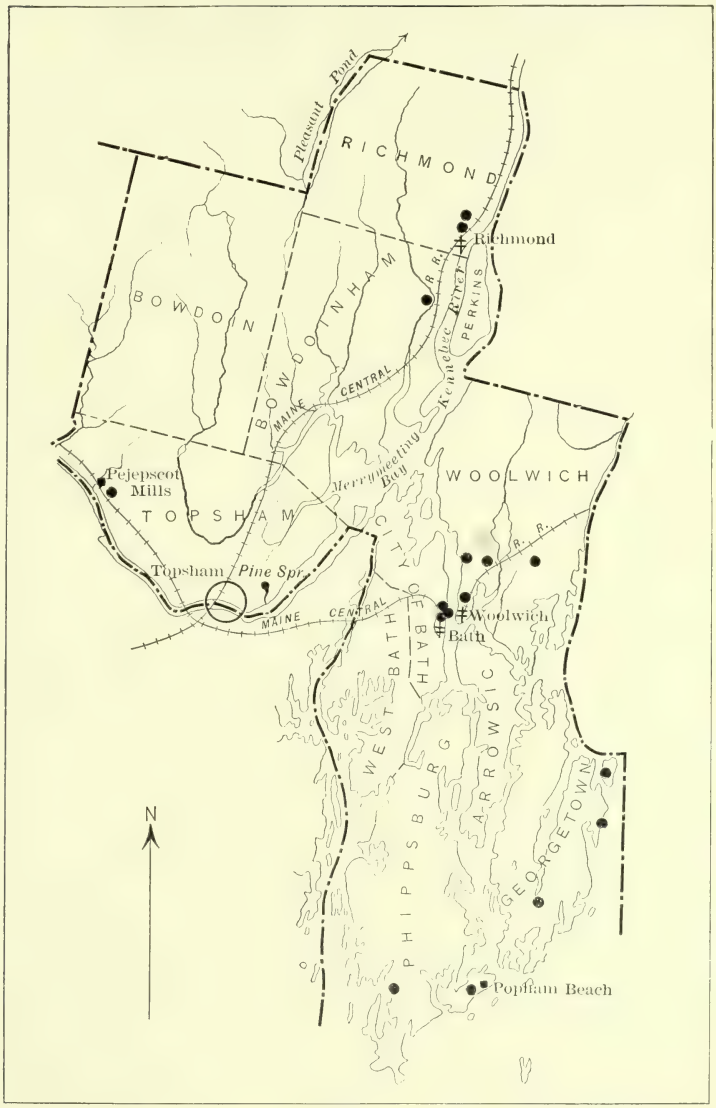
they can not be differentiated on any map. So far as observed in the field, the western portion of the county seems to be more gneissic and granitic than the eastern part, which is more schistose. The irregular proportions of the different rocks seem to have some effect on the quality of the water in various parts of this county and in adjacent counties.

Surface deposits.—The surface deposits of Sagadahoc County are not as thick as those in most other counties in Maine, owing largely to the fact that the county is cut up by many indentations of the sea and much opportunity has been given for the removal of the deposits by erosion. Along Kennebec River, up many of the small side valleys, and in a few sheltered places along the coast are small areas of clay, some of them 100 feet above sea level. These may be underlain by gravel. They are of considerable extent in the county and are overlain in many places by sand and gravel. Overlying the bed rock, as elsewhere in the State, is a thin coating of till, which in extreme cases is 20 feet or more in thickness. Borings in the valley of Androscoggin River in Topsham show that there the bed-rock floor of the valley is at least 155 feet below sea level, indicating a deep filling of gravel and an old gorge extending some distance back into the State.

WELLS.

GENERAL DESCRIPTION.

Only about 20 wells are known to have been drilled in Sagadahoc County. These are widely distributed, but are most numerous in Bath and Woolwich. They are mostly 6 inches in size, but a few 4-inch wells were sunk years ago. In depth they range from 40 to 335 feet, the deepest well in the county being that of the Pejepscot Paper Company, at Pejepscot Mills. An interesting fact is that although this well obtains only a small quantity of water a 40-foot well drilled for the same company a few feet distant obtained an inexhaustible supply, showing that the conditions are very uncertain. So far as can be learned from a study of the wells and records, it would not seem advisable to drill to great depths in this county. The limit should probably be about 200 feet. If a well reaches that depth without obtaining a sufficient supply the most economical procedure will be to drill a second well a short distance away. In the city of Bath most of the wells which were drilled years ago have been abandoned owing to the installation of a good city water supply. The abandonment has not been due in every case to the quality of the wells or the water. It can be stated, however, that the supplies in this county are not as good as in many counties of the State, and it is probable that not more than half the wells which have been drilled



0 5 10 MILES

- Successful well over 50 feet in depth
- Important spring
- Community having public supply from surface sources
- Community having public supply from wells
- Other important towns

MAP OF SAGADAHOC COUNTY.

Showing distribution of deep wells, important springs, and communities having public water supplies.

are in use at present. Four field assays (Nos. 150, 151, 107, and 199) and one laboratory analysis (No. 152) are given in the table. One mineral spring has been analyzed (Nos. 269–270a).

DETAILED DESCRIPTIONS.

Bath.—The city of Bath has an excellent water supply, piped under Kennebec River from Nequasset Pond, in Woolwich. For this reason no drilled wells have recently been sunk in the city. Some drilling was done years ago, mostly between 1883 and 1895. Eight or more wells were sunk to depths of 50 to 100 feet, and the yield ranged from 2 to 30 gallons a minute. Some of the water was used for boilers, but most of it was for ordinary domestic purposes. A few wells are still in use. The C. A. Hooker well is 100 feet deep and the water will rise to the surface at times. A considerable number of people in Bath use shallow dug wells. Many of them are in poor locations where they might easily be contaminated by surface drainage. It is advised that all such wells be abandoned. Two field assays of waters from Bath have been made (Nos. 150 and 151).

Woolwich.—Next to Bath, Woolwich has the greatest number of wells in the county. Most of these are about 100 feet in depth. They yield several gallons of water a minute and seem to be fairly satisfactory as sources of supply. A laboratory analysis of water from one of them is given in the appended table (No. 152).

Georgetown.—On McMahans Island a well of the Sheepscot Land Company was drilled to a depth of 246½ feet and obtained a good supply of water. At Five Islands Mr. George E. Hughes sunk a well to 242 feet. This is pumped by an electric motor and seems to be satisfactory. No other drilled wells are known in Georgetown.

Phippsburg.—Only one drilled well is known to have been sunk in the town of Phippsburg. This is a 96-foot well at Fort Popham, but no data regarding it have been received. Most of the wells in town are dug from 6 to 30 feet. At Popham Beach many driven wells have been sunk, getting fresh water from 6 to 15 feet below the surface, in sand. Below that depth salt water is encountered. The level of fresh water in these wells rises with the tide. Among the sand dunes are a number of small ponds, which indicate the level of water in the dunes. At Popham Beach several years ago a boring was made to a depth of 962 feet for coal, but without success.

Topsham.—The village of Topsham has combined with Brunswick in the Brunswick and Topsham Water District to install a supply of water from driven wells situated on the flood plain of Androscoggin River. The supply is so excellent that wells are unnecessary in these villages. At Pejepscot Mills a well 335 feet in depth gave only enough water for two families. A well was later drilled near by to a depth of 40 feet and obtained plenty of water. This is an example

of the extreme irregularity in the occurrence of rock water in this part of Maine. The formation here is mostly gneiss. In case any individuals or private companies in the village of Topsham desire water from wells in order to save water bills, it is probable that supplies can be obtained with success equal to that at Lisbon and Bath, a few miles to the northwest and east, respectively, of Topsham. The Pine Spring is situated in this town.

Bowdoinham.—The only drilled well known in Bowdoinham was sunk for Mrs. George L. Hinckley to a depth of 124 feet. This seems to have been a good well, but is not used on account of a broken pump. A dug well 40 feet in depth, 35 feet of which is in gravel and 5 feet in ledge, supplies 20 families. The rest of the wells here are less than 40 feet in depth. Two field assays (Nos. 107 and 109) have been made of well waters in this town.

Richmond.—A number of drilled wells have been sunk in Richmond in the past, but most of them are less than 50 feet in depth. One well 100 feet and one 65 feet deep are reported. Most wells in the village are abandoned, however, as there is a public supply from Kennebec River.

Other towns.—In the towns of Bowdoin, West Bath, and Arrowsic no drilled wells are known to have been sunk. While conditions are not as favorable as they are in Kennebec County, they seem to be better than in Lincoln County, and it is probable that drilling will be successful if the owner is willing to take the risk of possibly having to sink 2 wells before getting water.

SPRINGS.

General statement.—Springs are not especially abundant in Sagadahoc County, but some excellent ones are known. At Pejepscot Mills, in Topsham, the paper company owns an excellent spring which issues from sand and gravel in the bank of the river. The water is fine and cold and the rate of flow never varies. It is in such a situation that there seems to be no chance of pollution, and the water is highly prized by the people at the mill and by the inhabitants of the small village. A little spring house has been built and the water is pumped by means of a hand pump. One commercial spring is situated in the county.

Pine Spring.—As has been said, the Pine Spring is situated in the town of Topsham, 2 miles east of the village. It is owned by the Pine Spring Water Company, of Brunswick. The spring is situated in a small ravine in a sand plain. It is entirely surrounded by woods and as the only house in the vicinity is 500 feet distant, on the opposite side of the ravine, there is no chance for the water to become polluted. The water is colorless, odorless, and tasteless. The flow is 5 gallons

a minute and the measured temperature is 44°. The water is sold as "Pine Spring water" and is bottled for ginger ale and "soda." It is not called a mineral water. A crate of six half-gallon bottles retails for $1.50. Formerly a spring house was built over the spring, but it is now in disrepair. Such a house is unnecessary, as the spring is situated far from all buildings. The analysis of the water is given in the table (No. 269), having been recalculated from the analysis published by the company. Another analysis of the water made by W. W. Skinner, of the Bureau of Chemistry, United States Department of Agriculture, in connection with cooperative work on mineral waters conducted by the Geological Survey and the Bureau of Chemistry, is as follows:

Analysis of Pine Spring mineral water.

[W. W. Skinner, analyst.]

Gases (number of cubic centimeters per 1,000 grams at 0° C. and 760 mm. pressure):	
Carbon dioxide (CO_2), free	8.2
Carbon dioxide (CO_2), set free from bicarbonates on evaporating to dryness	2.4
	Parts per million by weight.
Phosphoric acid radicle (PO_4)	None.
Metaboric acid radicle (BO_2)	None.
Arsenic acid radicle (AsO_4)	None.
Silica (SiO_2)	7.4
Sulphuric acid radicle (SO_4)	1.05
Bicarbonic acid radicle (HCO_3)	12.86
Nitric acid radicle (NO_3)	None.
Nitrous acid radicle (NO_2)	Faint traces.
Chlorine (Cl)	4.20
Bromine (Br)	None.
Iodine (I)	None.
Iron and aluminum (Fe & Al)	.32
Manganese (Mn)	None.
Calcium (Ca)	2.14
Magnesium (Mg)	.79
Potassium (K)	.60
Sodium (Na)	3.49
Lithium (Li)	None.
Ammonium (NH_4)	.026
Oxygen to form Fe_2O_3 and Al_2O_3	.....
	32.876
Free ammonia	.025
Albuminoid ammonia	.005
Nitrogen as nitrates	Traces
Nitrogen as nitrites	Faint traces.
Oxygen consumed	6.00

PUBLIC SUPPLIES.

The city of Bath and the village of Richmond are supplied with water from surface sources, the former from Kennebec River and the latter from Nequasset Pond. Formerly the Bath supply was taken from 83 wells driven in sand, the average depth of which was about 20 feet. These wells were abandoned for the present supply. The village of Topsham has combined with Brunswick to obtain a system of water supply from driven wells on the flood plain of Androscoggin River, a short distance below the villages. This supply is described in connection with Cumberland County.

SOUTHERN SOMERSET COUNTY.

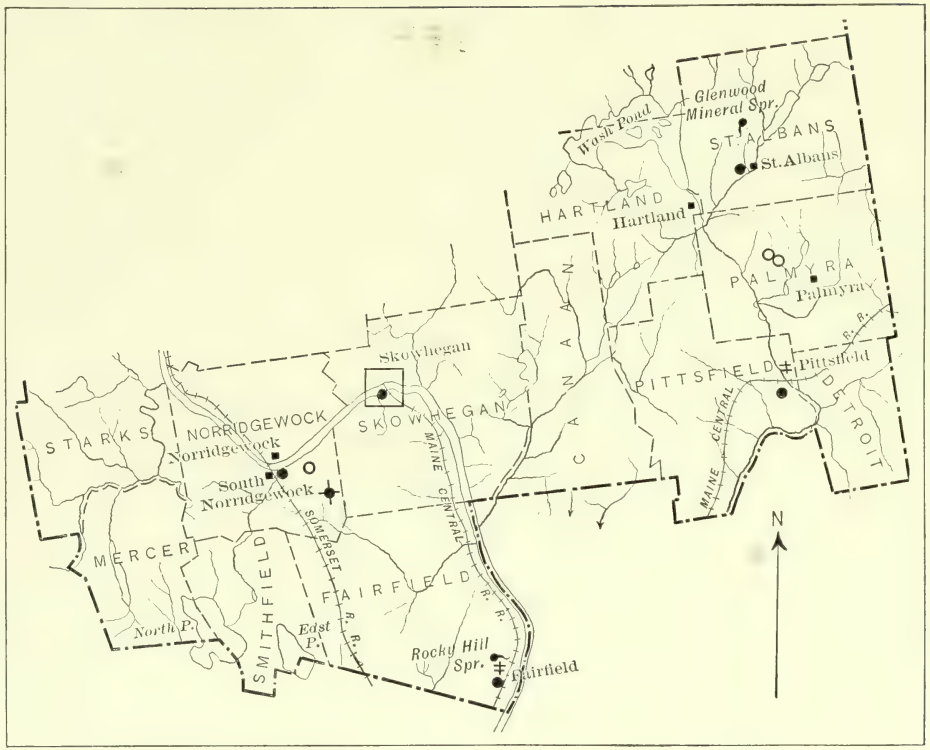
GENERAL DESCRIPTION.

Somerset County lies somewhat west of central Maine and extends north and south about half the length of the State, a distance of about 140 miles. The maximum breadth of the county is 45 miles and its area is 3,831 square miles. In this report only the southern part of the county is included. The population of the whole county according to the census of 1900 was 33,849. The largest town is Skowhegan, with a population of 4,266. The county is rather mountainous, its altitude ranging from 150 feet above the sea along Kennebec River to 3,600 feet at the summit of Mount Bigelow, but the highest point in the area here discussed is probably not over 2,000 feet high. Kennebec River is the principal stream, and flows through the center of the county in a southerly direction, except in the vicinity of Skowhegan, where it makes a marked bend. There are no important tributaries to the river in this part of the county, although Sandy River enters from the west in the vicinity of Madison, and Sebasticook River rises in the eastern part of the county and flows southward. Scattered throughout the county are a great many large and small lakes, of which Moose Pond is the largest within the area covered by this report. The only lines of transportation are the Maine Central Railroad, which runs southward from Skowhegan along the west bank of Kennebec River, and the Somerset Railway, which runs northward from Oakland through the center of the county to Moosehead Lake, outside the limits of the area here considered. A map showing the distribution of deep wells, important springs, and communities having public supplies forms Pl. XXI.

UNDERGROUND WATERS.

RELATION TO ROCKS AND SURFACE DEPOSITS.

Distribution of rock types.—The predominant rock formation of Somerset County is slate, and the whole northern part of the county is formed of this rock, with three important exceptions. These are



- ● Successful well over 50 feet in depth
- ○ Unsuccessful well over 50 feet in depth
- ✦ Flowing well
- Important spring
- ‡ Community having public supply from surface sources
- □ Community having public supply from springs
- ■ Other important towns

0 5 10 15 20 MILES

MAP OF SOUTHERN SOMERSET COUNTY.

Showing distribution of deep wells, important springs, and communities having public water supplies.

areas of granite. The first lies just west of Hartland and St. Albans and covers the southern part of Harmon, the western part of Hartland, the northeast corner of Cornville, and the southwest corner of Athens. The second granite area lies in the extreme southwest corner of the county and covers nearly the whole of Mercer, the portion of Norridgewock southeast of the village, and the west corner of Smithfield. The third granite area extends from Embden Pond, in Embden, northwestward beyond the limits of the area included in this report, and covers the northern part of New Portland, the northwestern part of Embden, the western edge of Concord, and probably the whole of Lexington and Highland plantations. Moderate amounts of water are found in granite, but the supplies are irregularly distributed. The granite is quarried in the vicinity of South Norridgewock.

The slate of this part of Somerset County is typical of the slate making up a large part of central Maine. It is a very fine-grained drab to black slate and splits parallel with the stratification. The strike is in general about N. 60° E. and the dip is as a rule nearly vertical, although in some places it is inclined. Locally this slate is slightly calcareous. Considerable water is found in this rock.

Surface deposits.—Along Kennebec River and in other sections where the land is rather low the surface is covered with sand and gravel and some clay, which form flat plains extending backward from the river in places for a mile or more. These plains are well developed in the vicinity of Skowhegan. One of these broad gravel-filled valleys lies between Norridgewock and North Fairfield. In these deposits good water is abundant and issues in the form of springs around the sides of the plains. The county contains also irregular gravel deposits. On the uplands the surface consists mostly of bowlder clay, which ranges from a few inches to 20 feet or more in thickness. In some of the mountain regions the surface is nearly bare of drift.

WELLS.

GENERAL DESCRIPTION.

Types of wells used.—The prevailing type of well in Somerset County is the old-fashioned open well, such as is common throughout the State. These wells are, as a rule, sunk in bowlder clay and gravel, although some of them are blasted a few feet into the rock. They range in depth from 5 to 40 feet. Generally they are successful in times of abundant rainfall, but are likely to run dry in summer.

Drilled wells.—Only about a dozen drilled wells have been sunk in Somerset County. In diameter they vary from 5 to 8 inches, but 6 inches is the prevailing size. The depth ranges from 26 to 157 feet, the most common depth being about 80 feet. They strike rock at 1 to 50 feet below the surface, and the greatest supply of water may

be found anywhere between the top and the bottom of the well. So far as known all the drilled wells have been sunk in slate, but there is no reason why they should not be successful in granite, as they are elsewhere in Maine. In one well the water rises to the surface of the ground.

Quality of water.—As few analyses have been made of waters from wells in Somerset County, not a very good idea can be given of the quality of water here. The total solids found in a well which was dug in drift and blasted in the underlying rock were 408 parts per million, and the hardness was 188. The amount of total solids in a drilled well was 56, and the hardness was 35. Another drilled well, 26 feet in depth, in slate and situated high up on a hillside, contained 29 parts of carbonates, a trace of sulphates, and 3.5 parts of chlorine. The details of these analyses are given in the table (Nos. 108 to 110). A good idea of the character of water which may be found in slate in this part of Maine may be had by consulting the analyses given in the table in connection with western Penobscot and northern Kennebec counties, on pages 78–79. The analyses of waters in granite in other parts of Maine are given on page 77. Analyses of several mineral springs are also given in the table (Nos. 271 to 273).

Quantity of water.—In general in Somerset County there seems to be plenty of water in the slates. Of the dozen wells drilled four have been failures, but three of these were situated on a barren hilltop where there was little soil and where there would seem to be little probability of finding water. The other well reported only a small fraction of a gallon per minute. One well was abandoned on account of poor water, and several have not been used since waterworks were installed in their respective towns. As the rock of Somerset County, with the exception of that in the granite areas, is similar to that of southern Penobscot County, where water is abundant, good supplies may also be expected in Somerset County.

Flowing wells.—A 25-foot well drilled on a slate hillside in the eastern part of Norridgewock obtained water which overflows the surface except in times of dry weather. With this exception no flowing wells are known in the county.

DETAILED DESCRIPTIONS.

Skowhegan.—Skowhegan, the county seat and largest town in Somerset County, is largely supplied with water by several aqueduct companies that obtain water from springs situated on the slopes of a sand plain bordering the village. The supplies are believed to be very good at present, but care should be taken to prevent their contamination by surface drainage. A full description of the public supplies of Skowhegan is given under the appropriate heading (pp. 209–210). The only drilled well in the village was sunk more than twenty years

ago for Mr. Levi P. Weston, on an island in the middle of the river. This well was pumped by a windmill, but was abandoned when the city waterworks were installed in 1888. On the sand plains surrounding the town there are a number of driven wells which seem to obtain adequate supplies of good water, and similar supplies may be obtained almost anywhere on the sand plains along Kennebec River.

Norridgewock.—On the sand plain south of the river in Norridgewock a large amount of water can be obtained by driven wells 10 or 15 feet in depth. The wells in the village are shallow. On the highlands east of the village of South Norridgewock are two drilled wells. One of these is 77 feet in depth and probably contains water, but has not been used because the owner had no deep-well pump. The other drilled well is situated in the eastern part of the town. It is only 26 feet in depth and overflows except in dry weather. It is siphoned down the hill to a farmhouse on the slope below and supplies water for domestic and farm purposes. It would seem that siphons might be more widely used in Maine. A field assay made of the water in this well is given in the table (No. 108).

Fairfield.—The village of Fairfield forms a part of the Kennebec water district, which obtains water from China Lake. In Fairfield an 8-inch well was drilled in 1884 to a depth of 91 feet. It is still used, and the water seems to be of good quality. As this town lies in the slate area in which abundant water supplies are found in neighboring parts of Penobscot County, it would seem that equally successful wells might be obtained here. The Rocky Hill Spring is situated in this town.

Pittsfield.—Pittsfield is supplied from the Sebasticook River. The water is reported as rather poor. In the village are a great many dug wells, 12 to 50 feet in depth, which are somewhat suspicious, as they are subject to contamination from surface drainage. One spring is situated near a number of houses and is probably not safe. Two or more drilled wells have been sunk in this village to a depth of less than 50 feet. The water is only of fair quality and is called hard. It is probable that more water could be obtained by sinking deeper, and it may be of better quality, although this can not be stated with certainty. An open well for Dr. F. J. Taylor was dug 20 feet and blasted 6 feet. The water has a fine taste and never gives out. A field assay of this water is given in the table (No. 110). A well drilled 47 feet for Mr. W. R. Hunnewell is reported to have a hardness of 35 parts (No. 109) while that of the Taylor well is 188. The total solids of the former were 56 and of the latter 408. In the Taylor well 48 parts of chlorine per million were found.

Palmyra.—Several drilled wells in Palmyra have attained fair success; several others, however, have not. An example of unsuccessful drilling is found on the estate of Mr. Perry Furbush, whose farm is

situated on top of a hill where the rock reaches the surface. Three wells were sunk. The first was dug and blasted 43 feet; then a horizontal gallery was run at right angles to the strike of the slate for a distance of 24 feet, but no water was found. This well was then drilled to 157 feet from the surface, when the tools became stuck and work was stopped. No water was found. Well No. 2 was drilled 80 feet through ledge and now supplies 20 to 30 gallons of water a day, summer and winter. Well No. 3 was also drilled 80 feet in ledge. The tools stuck at 80 feet, and the well had to be abandoned. This well was situated only 130 feet from the first. By pumping it dry every four hours 125 gallons of water a day could be obtained, which was not enough. As all the wells on this estate have proved to be practically failures, a spring some distance away on the hillside is used for watering the cattle. This spring is reported to issue from a vertical crack on a rotten seam parallel with the bedding of the slate. In other parts of town several drilled wells are supposed to have attained greater success, but these were not visited.

St. Albans.—At least one well is known to have been drilled in the town of St. Albans. The depth is reported to be 49 feet, and the yield is only a fraction of a gallon a minute. Deeper drilling in this town might meet with greater success in both the granite and the slate areas. The Glenwood Mineral Spring is situated in this town.

Hartland.—One or more wells less than 50 feet in depth have been drilled in the town of Hartland. The water was poor and they are not used. It would seem that by sinking to a greater depth water ought to be obtained in both the granite and the slate areas.

Madison, Anson, and Solon.—These three towns, although lying a little south of the northern extremity of the area considered in this report, have not been studied. They will be included in the report on the underground waters of northern Maine.

Other towns.—Other towns in this area obtain supplies entirely from dug wells and from springs. Where the wells are favorably situated the conditions are supposed to be good. In many places springs are of good quality and are much better and cheaper than wells.

SPRINGS.

General statement.—As stated above, springs are very abundant in Somerset County and are used for both public and private supplies, especially along Kennebec River. North of Madison several town supplies come from this source. Skowhegan and Fairfield also have spring supplies in part. Three mineral springs reporting sales are situated within the limits of Somerset County. These are the Glenwood Spring at St. Albans, the Pine Grove Spring near Pittsfield, and the Rocky Hill Spring at Fairfield.

Glenwood Spring.—In the town of St. Albans, about 2 miles north from the post-office, is the Glenwood Spring. The water is reported by the owner, Mr. C. A. Moulton, to issue from sand with a volume of 30 gallons a minute. It has no color, odor, or taste, and the temperature is said to be 48°. The water is shipped for table and medicinal use. An analysis, reported by the owner, has been recalculated into ions and parts per million and is given in the table (No. 272). The total solids amount to 67 parts. The following analysis, which gives the full composition of the water, was made by W. W. Skinner, of the Bureau of Chemistry, United States Department of Agriculture, in connection with cooperative work on mineral waters conducted by the Geological Survey and the Bureau of Chemistry.

Analysis of water from Glenwood Mineral Spring.

[W. W. Skinner, analyst.]

Gases (cubic centimeters per 1,000 grams at 0° C. and 760 mm. pressure):	
Carbon dioxide (CO_2), free	7.30
Carbon dioxide (CO_2), set free from bicarbonates on evaporating to dryness	10.00
	Parts per million by weight.
Phosphoric acid radicle (PO_4)	None.
Metaboric acid radicle (BO_2)	None.
Arsenic acid radicle (AsO_4)	None.
Silica (SiO_2)	11.00
Sulphuric acid radicle (SO_4)	3.62
Bicarbonic acid radicle (HCO_3)	54.71
Nitric acid radicle (NO_3)	1.55
Nitrous acid radicle (NO_2)	None.
Chlorine (Cl)	1.80
Bromine (Br)	None.
Iodine (I)	None.
Iron and aluminum (Fe and Al)	.35
Manganese (Mn)	None.
Calcium (Ca)	13.01
Magnesium (Mg)	2.49
Potassium (K)	.93
Sodium (Na)	3.92
Lithium (Li)	None.
Ammonium (NH_4)	.011
Oxygen to form Fe_2O_3 and Al_2O_3	.150
	93.541
Free ammonia	.01
Albuminoid ammonia	.01
Nitrogen as nitrates	.35
Nitrogen as nitrites	None.
Oxygen consumed	5.00

Pine Grove Spring.—About 5 miles southeast of Pittsfield is a spring known as the Pine Grove Spring. The flow is reported large, and the temperature is given as 48°. The water is sold in Pittsfield and vicinity.

Rocky Hill Spring.—The Rocky Hill Spring, owned by Mr. W. N. Osborne, is situated 1½ miles north of the village of Fairfield. The spring is said to flow 18 gallons an hour and to issue from slate. The flow diminishes somewhat in a severe drought. The temperature is reported as 46°. The water is colorless and tasteless. It is sold in Waterville and Fairfield. A sanitary anlaysis made in 1896 showed it to be of excellent quality. The mineral analysis, from the analysis advertised by the owner, is given in the table (No. 271). A more complete analysis was made by W. W. Skinner, of the Bureau of Chemistry, United States Department of Agriculture, in connection with cooperative work on mineral waters conducted by the Geological Survey and the Bureau of Chemistry. This is as follows:

Analysis of water from Rocky Hill Spring.

[W. W. Skinner, analyst.]

Gases (cubic centimeters per 1,000 grams at 0° C. and 760 mm. pressure):	
Carbon dioxide (CO_2 free)	7.20
Carbon dioxide (CO_2), set free from bicarbonates on evaporating to dryness	11.60
	Parts per million by weight.
Phosphoric acid radicle (PO_4)	None.
Metaboric acid radicle (BO_2)	None.
Arsenic acid radicle (AsO_4)	None.
Silica (SiO_2)	10.60
Sulphuric acid radicle (SO_4)	3.66
Bicarbonic acid radicle (HCO_3)	63.57
Nitric acid radicle (NO_3)	2.20
Nitrous acid radicle (NO_2)	None.
Chlorine (Cl)	2.80
Bromine (Br)	None.
Iodine (I)	None.
Iron and aluminum (Fe and Al)	.140
Manganese (Mn)	None.
Calcium (Ca)	13.29
Magnesium (Mg)	4.34
Potassium (K)	.85
Sodium (Na)	4.60
Lithium (Li)	None.
Ammonium (NH_4)	Traces.
Oxygen to form Fe_2O_3 and Al_2O_3	.060
	106.110
Free ammonia	Traces.
Albuminoid ammonia	Traces.
Nitrogen as nitrates	.50
Nitrogen as nitrites	None.
Oxygen consumed	3.50

PUBLIC SUPPLIES.

Skowhegan.—About half the inhabitants of Skowhegan obtain water from what is known as the "city water" system. This system is, however, owned by the Skowhegan Water Company, which has a contract to provide the village with fire protection. The water comes from a ponded brook in a valley on the eastern edge of the village and is believed to be of fair quality. There are also four aqueduct systems drawing water from springs situated in ravines in the sand plains which surround the village. These are the West Aqueduct Company, the Coburn Aqueduct Company, the Skowhegan Aqueduct Company, and the Niel Aqueduct Company. All these supply the part of the village situated north of the river. On the south side of the river there are a number of private systems.

The springs of the West Aqueduct Company are two in number and issue from the base of a sand and gravel plain on the northern and western edges of town. The plain is underlain by clay. One of these springs is situated 300 feet from the nearest house built on the plain above; this is probably safe. The other spring is 50 feet or less below a stable on the edge of the plain; this spring would seem to be dangerous and ought to be abandoned. The water is collected in two tanks built over these springs and runs by gravity to the houses where it is used. Most of West Skowhegan gets water from this system. The water is called excellent by the users. This is the largest aqueduct system, and supplies about 150 families. A field assay of tap water is given in the table (No. 273).

The spring of the Coburn Aqueduct Company is situated within a few hundred feet of the West Aqueduct springs, in another ravine. This water is of excellent quality and appears to be safe. The system is reported to supply about 100 families.

The Skowhegan Aqueduct Company's system is smaller, deriving its supply from a well and a spring situated on the edge of the plain on North street. The well is a large dug well, probably 15 feet in depth, on top of the plain and not 50 feet distant from two houses. The water is in sand, on top of clay. The company is reported to have 36 takers. The spring is situated not 20 feet from a house and on the slope below it. This situation appears rather dangerous and it would be advisable to abandon the spring.

The Neil Aqueduct Company obtains its supply from an old brickyard some distance down the ravine from the springs of the West Aqueduct Company.

All these supplies are gravity systems, and as the sources lie on the edge of the sand plain they can not reach the people living on the higher land. These families are supplied by "city water." Most of the patrons of the aqueduct water use spigots, which flow a

constant stream through a hole about one-twentieth of an inch in diameter through a glass tube. The rates are $6 a year.

The first aqueduct line is reported to have been laid in this village as long ago as 1830.

Other towns.—A part of Fairfield has a spring supply. Pittsfield and the rest of Fairfield use surface water.

PREDICTIONS AND RECOMMENDATIONS.

In Somerset County the conditions for obtaining underground-water supplies seem to be fairly good, but as yet they have not been fully developed. In a few places, as in some of the villages, water is obtained from dug wells which are evidently polluted by surface drainage and are unsafe. Where there is any suspicion about the quality of the water the dug wells should be abandoned for the public supplies or drilled wells. The latter are suitable for use nearly everywhere and are in many places better than the public supplies. Some springs have been seen which should not be used, but as a rule the springs in the county are well situated and are safe for drinking.

WALDO COUNTY.

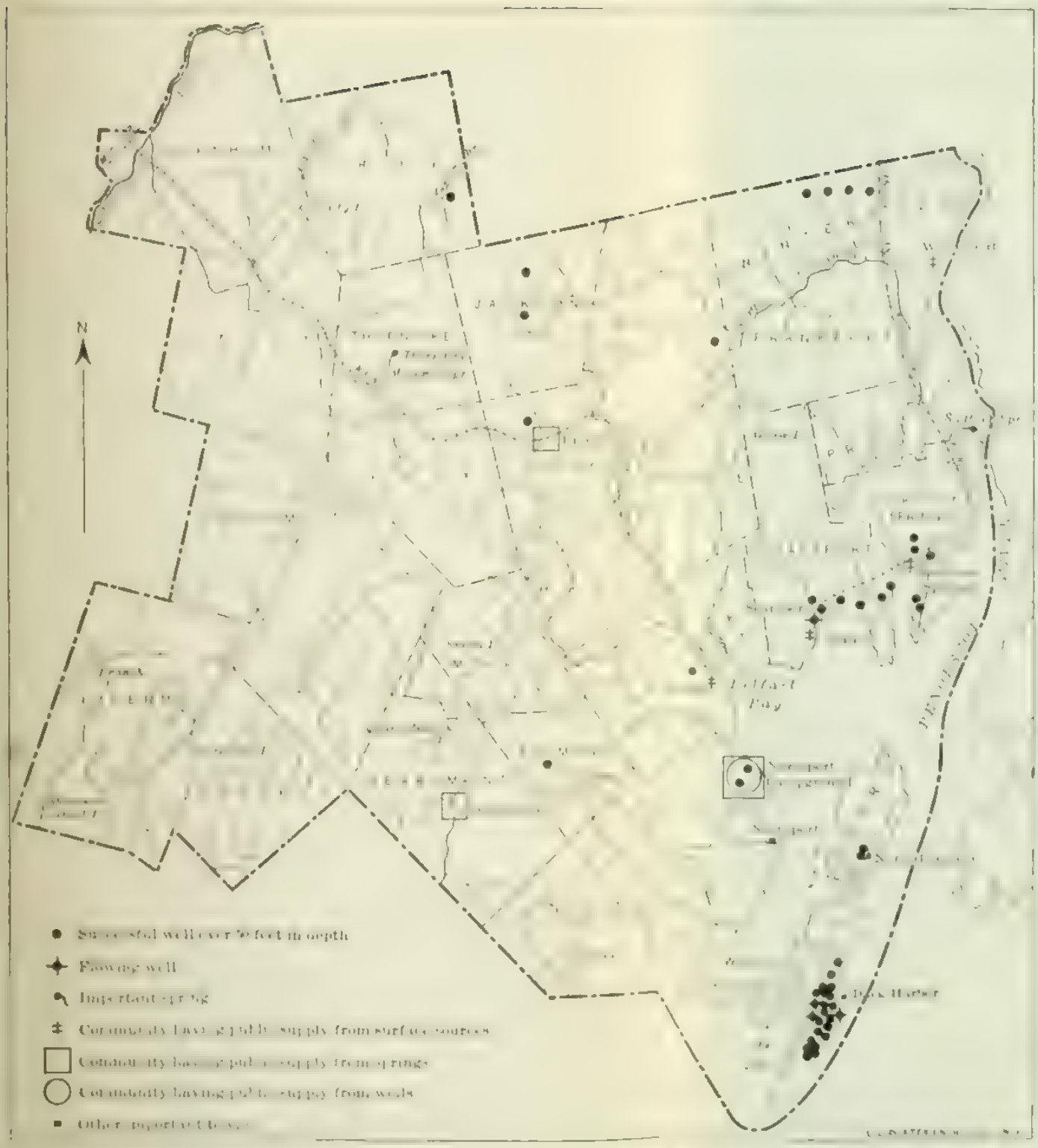
GENERAL DESCRIPTION.

Waldo County lies in southern Maine, just west of Penobscot River and Penobscot Bay. It is a small county, having a total extent north and south of only about 35 miles, and the same east and west. Its area is 748 square miles, and the population according to the census of 1900 was 24,185. Belfast, the principal town, contains 4,615 inhabitants. This county is moderately hilly and ranges in elevation from sea level to nearly 1,100 feet. It has no large streams except the Penobscot, on which it borders, but contains a few small lakes. Its transportation lines are the Maine Central Railroad, running northwestward from Belfast across the county, and the Bangor and Aroostook Railroad, which runs northward from Searsport. A map of Waldo County showing the distribution of deep wells, important springs, and communities having public supplies forms Pl. XXII.

UNDERGROUND WATERS.

RELATION TO ROCKS AND SURFACE DEPOSITS.

Distribution of rock types.—Probably about half of Waldo County is composed of slate. The area occupied by this rock lies northwest of a line drawn roughly from the southwest corner of the county northeastward to Penobscot River, on the border of Penobscot County. There is also a considerable patch of slate and slaty rocks southwest of Stockton Springs, which covers the greater part of the



MAP OF WALDO COUNTY

towns of Searsport, Belfast, and Belmont and smaller parts of Searsmont and other towns. Islesboro is also mostly slate, although thin and unimportant bands of limestone are reported to cross this island.

The principal granite area in Waldo County lies in the southeastern part of Winterport, the eastern part of Frankfort, in Prospect, northern Searsport, and eastern Swanville. Parts of Swanville, the greater part of Waldo, smaller parts of Brooks, Morrell, western Searsmont, southeastern Montville, Liberty, and southeastern Palermo are underlain by a complex consisting mostly of granite, gneiss, diorite, schists, and other rocks. Another arm of the complex enters the southern edge of the county and covers the greater part of Lincolnville and Northport, but also includes part of Searsmont and probably a corner of Belmont.

As a rule the slate of Waldo County strikes in a northeast direction, and the cleavage has generally about the same trend. The slate is hard and compact and the dip is always high. A small part of eastern Waldo County has been studied thoroughly by the geologists of the United States Geological Survey, and the results have been published in the Penobscot Bay geologic folio.[a] It is therefore possible to say with considerable certainty what kind of rocks are found in the various towns in this region. The distribution of these rocks will be described under the town headings.

Surface deposits.—The unconsolidated deposits forming the surface of Waldo County consist for the most part of bowlder clay, which ranges in thickness from 1 to 20 feet or more, but is commonly thin. This bowlder clay generally forms the surface on the hills where they do not consist of bare rock, but in the lowlands it is in many places overlain by various amounts of stratified sand and gravel, and here and there by clay. These deposits locally form flat plains, but are nowhere of great extent.

WELLS.

GENERAL DESCRIPTION.

Types of wells used.—The predominant type of wells in Waldo County is the open well. They vary in depth from 10 to more than 30 feet and are generally dug in gravel or bowlder clay, although some of them are blasted in rock. These wells are generally successful in wet seasons, but in summer they usually dry up.

Drilled wells.—A greater number of wells have been drilled in Waldo County than in any other county on the Maine coast except Cumberland. There are more than a hundred such wells within the limits of the county. They are mostly 6-inch wells, but a few 7 inches in size are reported, and a number of wells are 8 inches at the top and 6 inches at the bottom. One well was 10 inches at the top and 8

[a] Geologic Atlas U. S., folio 149, U. S. Geol. Survey, 1907.

inches at the bottom. In depth they run from 30 to 329 feet. Most of them have been successful, although a few have been abandoned owing to insufficient supply, and in one or two the quality of the water has not been up to the standard.

Quality of water.—The quality of water in Waldo County is generally good. In all, 14 analyses are known to have been made. Most of them are of slate waters, but a few analyses of water from other rocks have been made. The total solids reported range from 138 to 163 parts per million, and one well reports them as high as 234. The hardness runs from 85 to 152 parts, but is reported in only a few analyses. The carbonates range from none to 28, and the calcium from 8 to 47. Some reports of iron run as high as 10, but these are believed to be erroneous. A better idea of the quality of the water can be had from the table (Nos. 111 to 127, 153, and 154).

Quantity of water.—The quantity of water found in wells in Waldo County is extremely variable, depending on the situation, time of year, kind of rock, and other conditions. In some wells only a trace of water was found. In one of the wells situated at Cape Jellison the supply was 200 gallons a minute, according to the reports of the railroad company. Only a few failures have occurred in the county. In general the water seems to be best in slate. In the complex region indicated on the map (Pl. I) supplies will probably not be found to be quite as large as elsewhere.

Flowing wells.—Several flowing wells have been noted in Waldo County. Two of these are situated in the town of Islesboro and are deep drilled wells, probably deriving their head from near-by hilltops rising a few feet above the surface of the well. A similar well is reported at Searsport, but the hill from which its head is derived seems to be at a distance of several hundred feet. The flowing wells in slate of which these are examples are caused by water pressure due to the inclination of the joint cracks running from hills in the vicinity, and the flows are found where the intervening rocks are overlain by clay and hardpan, which close the joints at the surface.

DETAILED DESCRIPTIONS.

Belfast.—Belfast obtains its public supply from Little River, which enters the sea 2 miles south of the village. The water is poor, being taken from a very swampy reservoir near the mouth of the river. In summer it has a fishy odor. As far as health is concerned it is probably not dangerous, and if taken from a higher point on the same river and confined in a reservoir containing less vegetation the water would probably be satisfactory.

In the upper part of the village a few wells have been dug in clay and bowlder clay. These are situated near houses and are in danger of pollution from drainage. Some persons prefer the wells to the city

water, but the public supply is safer. One drilled well in town is 39 feet in depth, and the water is used for domestic purposes. The slate in this town is similar to the slate of Penobscot County and ought to give plenty of water, although its capacity has not yet been thoroughly tested by drilling.

Belmont.—The only drilled well in Belmont is that belonging to Mr. Horace Chenery. It is 187 feet deep, and slate was struck at 12 feet from the surface. The well was cased with 10-inch casing to rock, and 8-inch casing was then placed inside and the space between filled with cement, making it water-tight. The yield is reported as 19 gallons a minute, and the analysis (No. 111) records 138 parts per million of total solids.

Searsmont.—In Searsmont there are no drilled wells. The deepest well is dug 44 feet deep and supplies good water. A field assay (No. 201) shows 16 parts per million of carbonates. The public supply of Searsmont is obtained from springs. The village has a few driven wells, but none have been drilled.

Northport.—The town of Northport is underlain largely by a complex of slates and schists, with considerable granite and diorite and other injected igneous rocks. Northport Camp Ground is supplied by a public system from springs and a drilled well belonging to the Mountain Spring Water Company. The well is 168 feet deep, is situated on the hill in the upper part of the village, and supplies 27 gallons of water a minute. An analysis (No. 153) shows total solids amounting to 145 parts per million and a hardness of 87. Another well, 64 feet in depth, obtained a small amount of water. The total solids and the hardness are 234 and 126 parts per million, respectively. A full description of the deeper well is given under the heading "Public supplies" (p. 217).

Searsport.—Searsport is underlain mostly by slate and schist. There are, however, traces of other rocks in the town. The village until recently was supplied by two springs situated on the hillside 2 miles west of the village, but now buys its water from Stockton Springs, which obtains its supply from Halfmoon Pond.

The best drilled wells in Searsport are those of the Bangor and Aroostook Railroad (Northern Maine Seaport Railroad Company). One of these, situated at the terminal, is 329½ feet deep. This well yields 60 gallons of water a minute with a steam pump. A similar well at Kidders Point is 285 feet deep and yields 130 gallons a minute. The water is sold to supply steamships and is also used for running an electric plant.

In the village of Searsport there are several wells. Some of these are about 100 feet deep and give many gallons of water per minute. The well at the Searsport House is said to overflow the surface in wet weather. The quality of the water is very good. The common

constituents are reported in the analyses of the railroad wells (Nos. 118 and 123). As will be seen, the total solids range from 100 to 150. The water is excellent for drinking purposes, but it forms a small scale in locomotive boilers.

Stockton.—The village supply of Stockton Springs is taken from Halfmoon Pond. The railroad has a well at the "Y," one well directly east of the village, and two wells at Cape Jellison. These wells range in depth from 158 to 247 feet and yield from 10 to 200 gallons a minute. Of the wells at Cape Jellison one was drilled 158 feet, giving 12 gallons a minute, but the supply decreased; the other was sunk to 225 feet, and at that depth gave 200 gallons a minute. These wells are pumped by steam and electric pumps. Two analyses of water are given in the table (Nos. 112, 127). In both wells there is much iron, due to the rusting of the pipes, but the water is good. It is excellent for drinking, but some scale forms in boilers. There are several other drilled wells at Stockton Springs.

Prospect.—In the eastern part of the town of Prospect the Switzer Spring is situated. All wells in the town are shallow and none is known to have been drilled.

Frankfort.—Most of the wells in Frankfort are dug wells, but one or more drilled wells are reported. The water in the eastern part of town is mostly granite water; that in the western part is largely slate water. The wells in the western section will probably be somewhat the more successful.

Winterport. Winterport has a public supply from West Branch of Lowes Brook. There are no drilled wells in the eastern part of the village, but in the western part there are several, the conditions for water being better in that section. The supplies are obtained in slate similar to that at Bangor.

Monroe.—At least one drilled well is situated in the town of Monroe. This is a 7-inch well 61 feet deep. The water contains some iron, but is used for domestic purposes and for stock.

Jackson.—Several drilled wells in Jackson are between 45 and 65 feet in depth. One of them is a 9-inch well. The water from all of them is used for domestic purposes and for stock.

Brooks.—The public supply of Brooks is taken from two springs in the village. A few people use dug wells, some of which have caused sickness in the past. There are a number of drilled wells in town, but no information regarding them is at hand. There ought to be plenty of water in slate at this place.

Thorndike.—Wells have been sunk in the town of Thorndike, but no data have been received regarding them. The conditions ought to be as good as in other towns in the vicinity which derive their water from the slate formation.

Troy.—In Troy most wells are blasted and drilled in rock. The depth ranges from 20 to 70 feet, and plenty of water is obtained for domestic and farm purposes. Most of the wells are of the ordinary size, but in 1876 one 8-inch well was sunk. Conditions in this vicinity are probably good.

Islesboro.—Drilled wells are practically the only kind used in southern Islesboro, and the island contains more of these than any other town in Maine. It is occupied as a summer resort by many wealthy people, who can afford the best type of wells, and more than 40 have been drilled. The depths range from 60 to 398 feet, the common depth being 60 to 120 feet. There is generally plenty of water, and some wells report more than 15 gallons a minute. The 149-foot well of the Islesboro Land and Improvement Company supplies a large summer hotel and sometimes 10 cottages, the yield being 8 gallons a minute. Only two or three failures are reported. The majority of wells lie south of Dark Harbor, but a few are situated farther north. There are several drilled wells at North Islesboro.

In quality the water of the Islesboro deep wells is uniformly good. It varies, however, from hard to soft. One analysis reports total solids as high as 145 parts per million and a hardness of 86. The chlorine in three other wells varies from 7 to 33, and the carbonates, where determined, run between 85 and 127 parts. There is generally a trace of sulphate, but no iron. (See analyses Nos. 113 to 116.)

The predominating rocks on Islesboro are a series of volcanic rocks and interstratified slates, tuffs, etc. There are, however, a few narrow bands of limestone extending in a general north-northeast direction, and just west of Meadow Pond in North Islesboro is a small patch of quartzite. Several small areas of greenstone are found in the southern part of the main island and on some of the smaller islands of the town. The limestone is probably responsible for the hard water which is sometimes reported. The drift on the island is generally very thin, but where it is thick enough some dug wells are used. The water in these is likely to be softer than in the drilled wells. Some of the dug wells can not be pumped dry. The drilled wells are, however, always best for drinking. One drilled well enters a hard, granitic-looking rock at 20 feet from the surface. This is called "granite" locally, but is probably only a more metamorphic portion of sandy slate.

Well drillers report that 75 per cent of the water on Islesboro is found on the western side of the ridge. A popular belief on the island is that the deep-well supplies come from the mountains on the mainland. This is not impossible, but calculation based on the amount of rain water falling annually on Islesboro, and an estimate of the amount which is probably absorbed by the surface deposits,

show that there is plenty of water to supply all the dug wells without having to postulate such a distant source.

A well on Bevidges Point obtained salt water at a depth of 220 feet. This well was filled with Portland cement to a depth of about 200 feet, and now the water is excellent. Mr. Edwin Bevidge, on the same point, also obtained salt water, but it was not salty enough to injure the well for domestic purposes.

SPRINGS.

General statement.—Springs are very numerous in Waldo County, and some are used for domestic supplies. At the town of Brooks the public supply is derived from springs, and in Searsport spring water has been used in the past for public supply. The principal commercial springs of the county are the Switzer Spring, in Prospect, and the Thorndike Mineral Spring, in Thorndike.

Switzer Spring.—The Switzer Spring, owned by the Switzer Water Company, of Bangor, is situated in the town of Prospect, half a mile northwest of Prospect Ferry. The water comes from a fissure in granite and flows through about 20 feet of gravel, from which it issues in a good-sized stream. The yield is reported in the company's circular as 150 gallons a minute. The flow is reported to be constant, and pumping by a windmill does not lower it. The temperature is reported as 44°.

The Switzer Spring water is mostly carbonated and used for soft drinks, but a small amount is bottled and shipped as spring water. The water is pumped to the bottling house 100 feet away. Some of the residences in the vicinity use this spring water for drinking.

Thorndike Mineral Spring.—Three miles east of Thorndike post-office is the Thorndike Mineral Spring, owned by Mr. Ross C. Higgins. The water seeps out of a hillside with a volume estimated by the owner as a gallon a minute. The water is very clear, but has a strong odor and taste of sulphur. It does not carry any sediment. A white sulphurous deposit is said to be formed on rocks above the spring. The water is used for drinking and for medicinal purposes and is sold. No analysis is reported.

PUBLIC SUPPLIES.

General statement.—Several villages and towns in Waldo County have public water supplies. Of these Belfast, Searsport, and Winterport use water from surface surfaces. Brooks and Searsmont have spring supplies, and Northport Camp Ground has a supply from a deep drilled well and a spring.

Brooks.—The village of Brooks has been supplied since 1900 by the Ames Spring and the Ginn Spring, which flow by gravity into a 10,000-gallon tank. The system is owned by the Consolidated Water Company of New Hampshire. The Ames Spring is about 75 feet and

the Ginn Spring 125 feet above the tank. Forty-three families and business houses, constituting about three-fourths of the village, are supplied, and about 5,000 gallons of water are used daily. The town has 2 miles of 3-inch and 1-inch mains. The Ginn Spring is the larger of the two springs, varying in flow from 3 to 6 gallons a minute. The Ames Spring may flow 1 gallon a minute. There is plenty of water for all present needs. A sanitary analysis made in 1903 shows the water to contain 150 parts per million of total solids and to have a hardness of 113. The chlorine was normal, and nitrites and nitrates were absent.

Searsmont.—The water supply of the village of Searsmont has for over fifteen years consisted of a gravity system from a spring owned by D. B. Cobb & Son. The spring issues from bowlder clay in an open field. In use it gives a head which will raise the water 100 feet above the center of the village. The mains consist of about half a mile of 2-inch iron pipes. Ten families, or about half the village, use the water. The amount is more than sufficient for all immediate needs. The quality of the water appears to be first class, but it contains a little iron. There is a barn about 300 feet distant, along the hillside, but no trouble has been experienced with the water. As a precaution it would seem desirable to change to a spring higher on the hill. The boggy nature of the surface indicates that a spring could be obtained higher up.

Northport Camp Ground.—The village of East Northport, or Northport Camp Ground, has for nearly twenty years been supplied by gravity from a well and a spring owned by the Mountain Spring Water Company. The spring, situated 2½ miles back on the mountain, is used the year round, and the well situated on the hill above the village is used as an additional supply during two months of the summer season. The well was first drilled to a depth of 95 feet, but it could be pumped dry, so drilling was continued. The rock is supposed to be schist, struck at 50 feet from the surface. At about 150 feet the drill dropped 18 inches and all the water was lost. The well was deepened to 168 feet and the water can now be lowered 30 feet by pumping. It has been pumped seventeen hours with no signs of exhaustion. There are about 200 takers and 500 taps, making about 95 per cent of the summer population who use the public supply. The village has no fire hydrants. In the height of the season 20,000 gallons of water are used in twenty-four hours. The mains are reported to be 12 miles in length. They are 6 inches and 2 inches in size.

PREDICTIONS AND RECOMMENDATIONS.

The improvement of the waterworks belonging to the town of Belfast is important. The village now obtains its supply from a rather poor reservoir near the mouth of Little River. The water has a disagreeable fishy odor and its use is at times very unpleasant. It is not

supposed to be detrimental to the public health, and in spite of its poor taste it is believed to be better than the water taken from dug wells in the heart of the village. In order to give entire satisfaction, however, the supply should be improved.

It is suggested that if a reservoir were built higher up on the same stream, and if care were taken to remove decaying vegetable matter and other organic materials from the reservoir and banks, the present trouble might be avoided. It is also possible that treatment with a minute quantity of copper sulphate, by a competent engineer, might improve the condition of the water.

Another recommendation to be made in respect to Waldo County is that a larger number of drilled wells be sunk. Many dug wells that do not give proper satisfaction might be replaced by drilled wells with probably good results, as the slates of Waldo County seem to contain plenty of water.

SOUTHERN WASHINGTON COUNTY.

GENERAL DESCRIPTION.

Washington County lies in the southeastern part of Maine, being bounded on the east by New Brunswick and on the south by the ocean. The length of this county is about 90 miles and its maximum breadth about 60 miles. The total area is 2,456 square miles, and the population according to the census of 1900 was 45,232. The largest city is Calais, with a population of 7,655, and the next largest is Eastport, which contains 5,311 inhabitants.

Washington County may be conveniently subdivided into three sections. The southernmost is a narrow strip along the coast, which contains a few small cities and towns. The central section, covering by far the greater part of the county, is an uninhabited wilderness. A few miles of the northern part of the county, near the Maine Central Railroad, also is somewhat settled and contains many farms. The area described includes the coast section and about half the wilderness section. The only railroad in the region covered by the report is the Washington County Railway, which crosses within a few miles of the coast, from Ellsworth, in Hancock County, to Calais and Eastport, on the eastern boundary of Washington County. Calais lies somewhat outside the area of this report as defined in the introduction, but it is included here in order to make a unit in discussion of the southern section of Washington County. Pl. XXIII is a map of southern Washington County showing the distribution of deep wells, important springs, and communities having public supplies.

This county is unusually well supplied with surface water, the principal rivers being the St. Croix, dividing Maine from New Brunswick, the Machias or Kowahskiscook, Pleasant River, and Narra-

- ● Successful well over 50 feet in depth
- ○ Unsuccessful well over 50 feet in depth
- ✦ Flowing well
- Important spring
- ‡ Community having public supply from surface sources
- □ Community having public supply from springs

MAP OF SOUTHERN WASHINGTON COUNTY.

Showing distribution of deep wells, important springs, and communities having public water supplies

guagus River. Throughout the wilderness there are abundant lakes, some of them 5 to 10 miles in length. The county is fairly hilly away from the coast, but not so rough as the adjacent part of Hancock County.

UNDERGROUND WATERS.

RELATION TO ROCKS AND SURFACE DEPOSITS.

Distribution of rock types.—Probably one-third of the area considered in this county is underlain by granite. A band of this rock which has a width of 10 to 20 miles extends from the southwest corner of the county, in the vicinity of Millbridge, northeastward to the vicinity of Calais. Another granite area extends from Hancock County across the boundary a short distance into Washington County. The areas mapped as granite in Washington County include small areas of diorite, a rock somewhat similar to granite, but darker and more basic.

Between the two principal granite areas, occupying most of the region north of the Washington County Railway, between Cherryfield and Addison, is a large slate area. The region lying southeast of the railway, between Machias and Pembroke, consists to a large extent of slate, but includes also some volcanic rocks. Probably the most extensive of these lie in the extreme southeastern part of the State. Some unmetamorphosed siliceous shales occur in the southeastern portion of the county.

In the towns of Perry and Robbinston is an area known as the Perry Basin, which is composed of rocks of different types from those found elsewhere in Maine. These are mostly conglomerates, sandstones, and some lavas. The sedimentary rocks here contain fossils, and by these their age is known to be Devonian.

Surface deposits.—The surface deposits of Washington County differ greatly in character. In many parts of the county there are areas of several square miles which are made up almost entirely of plains and undulating deposits of gravel and sand, in places 100 feet or more in thickness. One of these areas, situated in the town of Columbia and vicinity, consists of a flat plain 250 feet above the sea and several miles in length. Underneath the gravel deposits and covering a large portion of the bed rock of the county is a thin coating of till. Small areas along the coast and near the mouth of the principal streams consist of clay.

WELLS.

GENERAL DESCRIPTION.

On account of the great abundance of good spring water in Washington County the proportion of wells is not great. Throughout the country districts the use of springs is probably fully as extensive

as that of dug wells. The known drilled wells exceeding 40 feet in depth number only 12. These are mostly situated in the extreme east corner of the county, but there is one drilled well on Roque Island and one at Jonesport. Three deep driven wells have been sunk at Columbia Falls.

Little is known of the quality of well water in Washington County. Two laboratory analyses (Nos. 158 and 191), however, are reported, and several field assays (Nos. 190, 192, 193, 157, and 159) have been made. Wells in sand and gravel were found to be low in mineral matter, but those in greenstone were high. For analyses of granite waters persons interested are referred to page 77, where they appear in connection with the descriptions of other counties. The table also contains several analyses and field assays of springs (Nos. 275 to 284), some of which are of great mineral purity.

DETAILED DESCRIPTIONS.

Calais.—The city of Calais has taken its public supply from St. Croix River. The water was poor, however, and it has recently been abandoned for a spring supply brought from St. Stephens, New Brunswick. The wells in the city are mostly shallow. Several drilled wells are not used. There is no reason, however, why plenty of good water may not be obtainable by drilled wells in that region, as good wells have been obtained in the same granite rocks across the river.

In the country districts of Calais springs are largely used. These generally emerge from till or sand; one spring, however, was seen issuing from a crack in diorite. Some wells in town are sunk in clay. The water in these is generally poor. In the vicinity of Red Beach there are many granite quarries. No water was seen in them, but its absence was probably due to the small amount of soil on the hills where the quarries are situated, as granite generally contains water. The only reports of the composition of water in Calais are given by a laboratory analysis and a field assay of water from a 44-foot bored well in sand and gravel (Nos. 190 and 191).

Eastport.—Eastport is underlain largely by basic volcanic rocks which were originally lava flows. The city obtains its public water supply from Boydens Lake, in the town of Perry. The one drilled well in town is owned by the Seacoast Canning Company. It is 408 feet in depth, drilled in the bottom of an old quarry in the basic lavas. The rock is very hard for a depth of 250 feet, and several drills were broken, but below that depth the formation is softer. Most of the water was obtained at 345 feet, but small amounts were found at other levels. At times the water overflows the bottom of the quarry. The water was lowered 28 feet when pumped with an ordinary steam pump, and the amount was found to be too small for use. In 1906

pipes were run down 225 feet and a deep-well pump was installed. An attempt was made to use a force pump, but the rock was found to have been so broken up by blasting in the quarry that the water was forced by the pump into the fissures of the rock instead of out of the mouth of the well. In a test with a 3½-horsepower gas engine the water was lowered 75 feet and 60 gallons a minute were obtained, but it is not believed that the well would yield that amount by continuous pumping. An analysis of this water given in the table (No. 158) shows 413 parts of total solids, 48 parts of silica, and 71 parts of sulphates. This analysis is interesting, as it is the only one available of water from greenstone in Maine.

A large part of the peninsula of Eastport is bare rock, but there is some clay and gravel. A section of a dug well on the outskirts of the city is as follows: Soil, 3 feet; gravel, 5 feet; blue clay, 20 feet.

Some wells situated 50 to 80 feet above tide on the borders of the village obtain plenty of water below the bed of clay. Several of these were abandoned because they contained salt water. At a time when it was desired to supply the city by underground water a 40-foot test well was driven for the waterworks. This well flows at the surface and is used by farmers in the vicinity. The water is somewhat salty.

Lubec.—Lubec has an excellent water supply from springs situated west of the village. This system is described on pages 224-225. In the village of Lubec there are three drilled wells, and at North Lubec there are three more. The latter were drilled for the Seacoast Canning Company and are used and pumped by a windmill. In Lubec a well 100 feet deep was sunk for a hotel owned by Mr. W. J. Mahlman. Water was obtained at 96 feet and was pumped by a windmill. It was good water, but as only 8 gallons a minute were obtained the well was abandoned when the city water was installed. The well of the Lubec Sardine Company was drilled 165 feet and scarcely any water was found.

The rocks at Lubec are slates intruded and metamorphosed by large masses of gabbro. West of the peninsula the drift is generally thick and there is some clay. The field assay of one 30-foot well in clay is given in the table (No. 166).

Perry.—All wells in the town of Perry are open wells. In most of those which are sunk in clay the water is "brackish." The town is reported to be abundantly supplied with springs which issue from volcanic rock, sandstone, and clay. The flow is reported as much as 20 gallons a minute in wet weather and a little less in dry weather. A single field assay of water from a dug well is given in the table (No. 202).

Pembroke.—The general depth of wells in Pembroke is 5 to 30 feet. They are all open wells and are mostly dug in till and gravel.

Machias.—The town of Machias uses Machias River water. There are few wells in the town, and all are open wells. Some of the shallower ones penetrate clay and obtain water in gravel at an average depth of about 20 feet. Many families near the village use spring supplies. Some of the springs flow as much as 5 gallons a minute.

Marshfield.—There are no drilled wells in the town of Marshfield, and water is obtained from dug wells and springs. An analysis has been made of one 21-foot well which penetrates clay and enters gravel. Most of the wells run low or dry up in summer. Some persons haul water by hand from near-by springs.

Whitneyville.—The wells in Whitneyville are not more than 20 feet in depth. Some are in gravel and some in clay, and several rest on rock. The wells run dry during the summer and the owners haul water to their houses. At a few houses springs are used.

Jonesboro.—All wells in the town of Jonesboro are dug. One well is situated 50 feet from a granite ledge and is dug 7 feet in bowlder clay. This well overflows the surface. A field assay is given in the table (No. 174). One of the interesting features at Jonesboro is the granite water which seeps out of the horizontal joints, as shown in Pl. III, *A*. This illustration shows that there is plenty of water in granite at this place. A single field assay (No. 174) of water in bowlder clay has been made.

Machiasport.—The wells of Machiasport are mostly dug wells, 30 to 40 feet in depth, in sand and gravel. There are some springs in the town. The sardine factory obtains its water from a reservoir supplied by springs.

Jonesport.—Most of the inhabitants of Jonesport use shallow wells and springs. One dug well near the shore is reported to rise and fall with the tide, but the water is fresh. The well of the Seacoast Canning Company is 384 feet deep, in diorite. The water is used for drinking and the yield is reported to be 2½ gallons a minute. It is called hard water. A field assay of this water is appended (No. 159).

On Roque Island the water is said to occur at the contact between the volcanic rocks and the underlying sedimentaries. The well of Mr. George A. Gardner is pumped by a gasoline engine and gives enough water for domestic purposes. It can be pumped dry in twenty minutes, but will fill again in about the same length of time.

Addison.—The village of Addison Point has a public supply from springs which are described under the heading "Public supplies;" otherwise, the inhabitants use only dug wells and springs. One well, 21 feet in depth, penetrated two beds of clay and obtained water in gravel. The Addison Mineral Spring is situated 2 miles southeast of Addisonport.

Columbia Falls.—About half the houses in Columbia Falls are supplied by two springs. The water system is described under the head-

ing "Public supplies." The rest of the inhabitants use dug and driven wells. At Logie's canning factory there is a driven well 72 feet in depth, in which the formation consists entirely of sand. Three gallons a minute are obtained near the bottom of the well. Several other deep driven wells are reported in the town. These generally go through the clay into underlying gravel.

Harrington.—The village of Harrington is supplied by two spring systems, one of which is situated one-half mile northeast of the village and the other 2 miles west of the village, in the town of Columbia. These systems are fully described under the appropriate heading (pp. 225-226). A large part of the town consists of clay. The wells are mostly dug, but some are driven. Many of them go through 25 to 30 feet of clay and enter gravel.

Millbridge.—Millbridge has a public supply from springs situated in the hills a mile west of the town. These springs are fully described on pages 226-227. There are a few wells in the village, but these are mostly abandoned, as they enter a clay bed 35 to 40 feet in depth, in which poor water is found. One well was dug 40 feet and entered a layer of "flats mud" and is now brackish. People who do not use the aqueduct water get their supply from cisterns. There are no drilled wells in the town. The field assay of a shallow bored well in gravel is given in the table (No. 193).

Cherryfield.—The village of Cherryfield obtains water from springs by several small aqueduct systems. These are described more fully under "Public supplies." Some springs supply only two or three families. A few persons have cisterns. There are a number of wells 10 to 40 feet deep in gravel. The water of the wells and springs is good and is never exhausted.

Columbia.—The town of Columbia has few inhabitants and nearly everybody uses water from dug wells and cisterns. In the northern part of the town is a flat plain known as Pineo Ridge, or Blueberry Barrens, standing at an elevation of 250 feet above the sea and having a steep northern slope and deep ravines on its southern slope. These ravines contain many springs of excellent water. The public supply of the town of Harrington comes from springs situated in a swampy depression on a sandy slope in the southwest corner of Columbia.

SPRINGS.

General statement.—Springs are very abundant in Washington County. They are used by a large proportion of the inhabitants of the country districts for drinking purposes, and are also used by many communities for public supplies. The towns of Lubec, Harrington, Millbridge, Addison Point, Calais, Columbia Falls, and Cherryfield all have excellent water supplies from springs. There is at least one commercial mineral spring in the county.

Addison Mineral Spring.—Addison Mineral Spring, owned by the Addison Mineral Spring Company, is situated in the town of Addison, about 4 miles from Columbia station on the Washington County Railway. The spring has been known for a great many years. It was bought by White & Nash about twenty-five years ago, and the water was shipped for a time in barrels. Steps are now being taken to shut out the surface water and otherwise improve the spring. A concrete reservoir 12 feet in diameter and 6 feet in depth has been constructed, in the center of which is the spring. The reservoir generally contains about 3½ feet of water. The owners report the flow to be about a barrel a minute. It bubbles up through coarse gravel overlain by about 4 feet of clay. The run-off contains a considerable deposit of iron.

The composition of the water is given in the table (Nos. 275 and 276). It will be seen that the total solids are 139 parts per million, which is high for a Maine spring water. The water is also said to contain gases, "principally nitrogen, oxygen, and carbon dioxide, with a little hydrogen sulphide." A sanitary analysis in 1906 showed it to be suitable for drinking.

PUBLIC SUPPLIES.

General statement.—Notwithstanding the fact that the villages in Washington County are mostly small, several of them have wisely established public water supplies from the best sources. Machias has a supply from Machias River. Eastport obtains water from Boydens Pond. Calais formerly used St. Croix River water, but this was poor and recently a supply has been installed from St. Stevens, New Brunswick, which seems to be excellent. With these exceptions all the towns having public supplies obtain their water from pure springs issuing from sand and gravel deposits. The communities having such supplies are Lubec, Harrington, Millbridge, Addison Point, Columbia Falls, and Cherryfield.

Lubec.—The village of Lubec owns a system of waterworks piped from a spring situated in drift deposits about 2 miles west of the village. The spring issues from the side of a clay plain, but there is probably gravel and sand underneath. The surface behind the spring is composed of bowlder clay and is covered by large bowlders. The rock is said to lie 6 feet below the surface. There are no houses within a distance of more than 1,000 yards back on the hill, and there is no chance of the spring becoming contaminated by surface drainage.

Originally this spring was in private ownership, but five years ago it was bought by the town at a cost of $800, which included a little land about it. This whole hillside appears to be honeycombed with springs, and the water bubbling up out of the sand is very pure and clear and of excellent quality. A small shed has been built over the

spring. The flow is reported to be 100 gallons a minute, and an old resident says it has not diminished in volume during his lifetime. An analysis of the water showed 102 parts per million of total solids, the various constituents of which are reported in No. 282 of the appended table. From the spring the water flows by gravity to a 500,000-gallon reservoir dug in stony bowlder clay a few hundred feet distant. From here it is pumped to the village under a pressure of 25 to 45 pounds.

Harrington.—The village of Harrington is supplied by two private companies taking water from springs. The larger one of the two companies is the Quantabacook Water Company, which draws by gravity from a spring situated about 2 miles northwest of the village. This system is owned by several prominent citizens of the town and supplies about 60 families. The waterworks date back to the year 1861, thus being one of the oldest water systems in Maine. In that year wooden pipes were run to town, and some of the original pipes are still in use. In clay their condition deteriorates very little. In gravel, however, it has been necessary to change to iron. The wooden pipes consist of two half logs, put together side by side, with a 2-inch hole bored in the center.

In exact geologic occurrence the water bubbles up out of the sand in a swamp situated near the base of a long, gentle slope of sand and gravel probably underlain by clay. A stick 15 feet long was thrust down into the spring and did not reach the bottom. There are no houses in the vicinity, and the water may be said to be perfectly safe as regards sanitary quality. It is clear and has a fine taste and a measured temperature of only 44°. The flow does not vary with the season. The spring is covered with a small spring house. A fair-sized brook is formed and much more water runs away than can be used. At present about 300 persons are supposed to use the water, and it is said that four times as many people could be supplied. The rates are $8 for a family, without restrictions. The spring is situated 60 feet above the village and therefore gives a good pressure. The head is said to have diminished somewhat owing to the rotting of the wooden pipes. A field assay is given in analysis No. 278.

The eastern half of the village of Harrington is supplied from a spring situated in sand and gravel deposits about one-half mile northeast of town and not far from the railroad. It is owned by various members of the Nash family. The surroundings are thickly wooded and the water bubbles up similarly to that of the spring owned by the Quantabacook Company. It is supposed to issue from sand near the top of the underlying clay. Although the soil is so thick that the spring can not be seen, the water constantly over-

flows and runs off in the form of a small brook. The water is excellent, is very clear, and has a temperature of 42°. A small spring house is built over the spring.

This company has about 40 takers on its lines. It has no charter, but is a rather old company and still uses wooden pipes. The supply is not as large as that of the Quantabacook Water Company, but there is plenty for all who use it, and the spring is so situated, in the woods and far from any houses, that there is absolutely no danger of its becoming contaminated. The water of this company is similar in quality to that of the Quantabacook Company, being very low in mineral and organic matter. It is said that since these water systems have been installed no case of typhoid fever or diphtheria has originated within the limits of the village.

Millbridge.—The village of Millbridge is supplied by the Millbridge Water Company, which takes water from a spring and a bored well situated in the woods about a mile west of the village. The company was chartered in 1895 and the system was started in 1896. The Millbridge Water Company bought out the old wooden aqueduct company which had been in existence for ten or twelve years and had run a small plant accommodating from 30 to 40 houses.

The spring and the well are situated on the eastern side of a gentle bowlder-clay slope which is believed to be underlain by gravel. There are no houses within a distance of three-quarters of a mile, and the water can be said to be absolutely safe from contaminating influences. The water from the spring is piped to town. The well, however, situated near by, is fitted with a windmill and a kerosene engine, which are used in case of drought. The well was dug in 1898, at a time when the spring was rather low. When the wind blows in summer the well water enters the mains and is mixed with spring water. In winter the well is never used. The well passes through 16 feet of till and enters gravel. It is reported that when it penetrated the clay into underlying gravel the water gushed up 12 feet into the air. When not used it now overflows in a small stream. It is curbed with ordinary glazed sewer pipe. The water of this well can be lowered within 4 feet of the bottom by pumping, but no lower.

There seems to be plenty of water at this place, but if it ever is exhausted it will be a very simple matter to dig out other holes such as the well above mentioned. According to surveys made by the company the spring is situated 69 feet above the drawbridge across Narraguagus River at Millbridge. The well is 38 feet below the level of the spring and is only 17 feet in depth. The pump at the well carries the water to a reservoir 50 by 30 feet in size situated near the spring. The pressure is 48 pounds. The owners report that there is no detectable difference in quality between the water taken from

the spring and that taken from the well. Both are fine, clear water with little or no taste. The results of field assays are appended (Nos. 193 and 283). The water mains of the Millbridge Water Company are 6 inches in diameter. The wooden pipes used for years were abandoned and now iron pipe is used.

About 120 water takers are said to be on the lines, including the mills and sardine factories. Probably about 600 people use the water. Nine-tenths of the houses on the south side of the river use it, but none on the north side. The rates are $10 to a family for a single service, with no restrictions as to the use of the water.

Cherryfield.—Cherryfield is supplied in part by water from the West Side Aqueduct and the East Side Aqueduct companies, the water being taken from two springs situated a short distance from the village. The water issues from gravel about 100 feet above the village. The people who do not use these supplies generally have private aqueducts running to springs in the hillsides. A few, however, use dug wells 10 to 40 feet in depth. All this water is found in gravel below clay. The principal system was installed in 1875. The aqueduct companies use wooden logs for piping. These are said to have rotted out in gravel, but answer the purpose very well in clay. The springs are said to yield plenty of water during the winter, but sometimes they are low during the summer.

Addison Point.—The village of Addison Point is supplied by the Addison Point Aqueduct Company, which has a spring in sand 7 miles from the village and distributes the water by direct pressure through logs. The head is about 60 feet.

PREDICTIONS AND RECOMMENDATIONS.

On account of the sparse population of Washington County few recommendations are necessary. All the public water supplies seem to be of excellent quality, and their use is recommended above that of ordinary well water. In few places does it seem necessary or advisable to spend money in drilling deep below the surface. In communities where well water is scarce and people desire to save water bills drilling may perhaps be done to advantage, as it has been done by several of the canning companies; and when the islands along the coast come to be used more extensively as summer resorts it is probable that deep wells will be needed in order to obtain sufficient supply. Deep-well water can be obtained nearly everywhere. In some of the volcanic areas, however, as at Lubec and Eastport, the quality and amount will be rather uncertain. The poorest water supply is that of Eastport, and the sanitary conditions in this town might be much improved.

YORK COUNTY.

GENERAL DESCRIPTION.

York County is the extreme southwestern county of Maine, bordering on the ocean and on the State of New Hampshire. Its greatest length is 50 miles from north to south and its breadth is 30 miles. The total area is 957 square miles, and the population according to the census of 1900 was 64,885. The largest city is Biddeford, containing 17,165 inhabitants; Saco had 6,122 and Sanford 6,078. The principal rivers are the Piscataqua, separating Maine from New Hampshire, and Saco River, which lies in the eastern part of the county.

The principal transportation lines are the Eastern, Western, and Portland and Rochester divisions of the Boston and Maine Railroad, which cross the county from northeast to southwest, and the York Harbor and Beach Railroad, which connects Portsmouth, N. H., with York Beach. In topography the county is very diversified, ranging in altitude from sea level to about 1,300 feet. The coast is in many places very rocky, but it also contains a number of beaches which are among the finest in the country and are used extensively for summer resorts. A map of York County showing the distribution of deep wells, important springs, and public supplies forms Pl. XXIV.

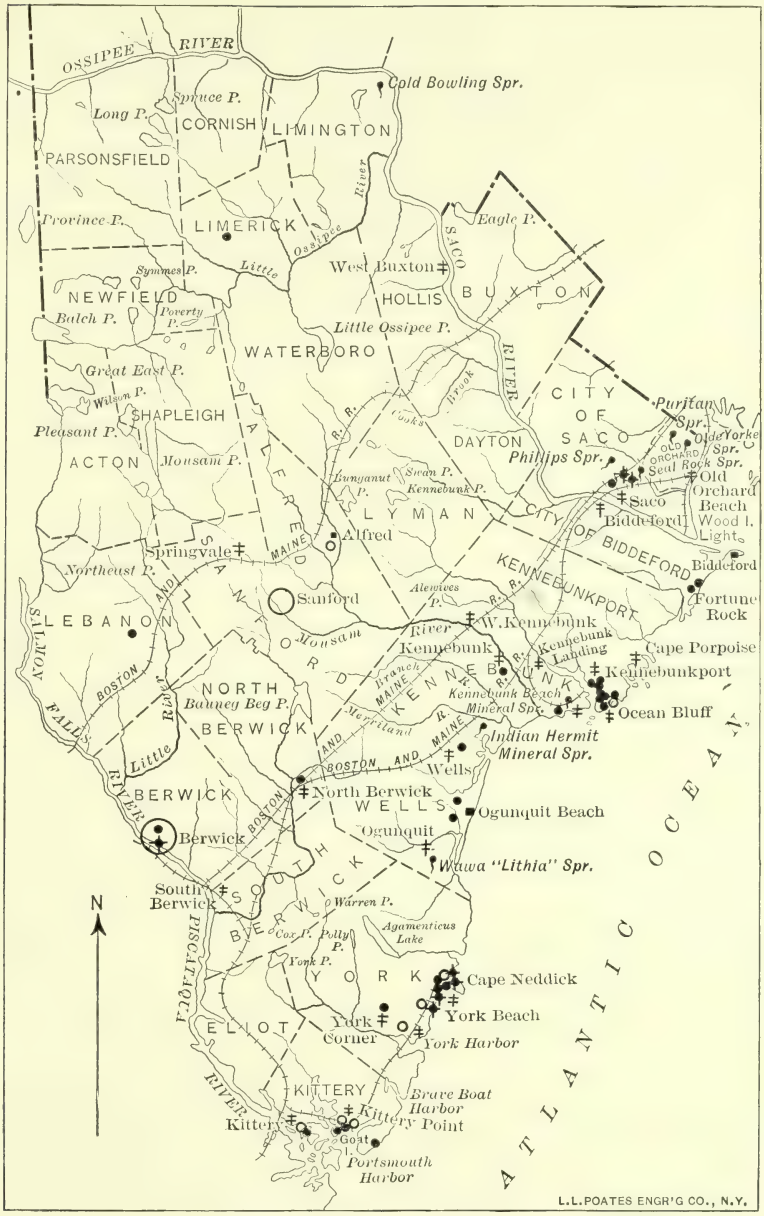
UNDERGROUND WATERS.

RELATION TO ROCKS AND SURFACE DEPOSITS.

Distribution of rock types.—The rocks of York County consist chiefly of slate and granite. They are rather irregularly distributed, but in general the granite can be said to occupy a belt from 5 to 10 miles in width, extending southward from Limington and Hollis to the vicinity of Alfred and Lyman, where it splits into two belts, one of which reaches the coast in the town of Kennebunkport and the other extends as far south as South Berwick and northern York. Outside the granite area the rock is generally slate and schist, which range in character from a rather fissile shaly rock to a hard, dense black slate which is in many places considerably metamorphosed. Much of the rock mapped as slate is in reality schist or quartzite. Both the slate and the granite are cut by a large number of trap dikes.

The prevailing direction of the strike of the slate is from N. 60° to 80° E., and the dip is generally 75° NW. or SE. to vertical. In only a few localities are the dips low. In places the strata are much contorted. The old metamorphic rocks are cut by numerous dikes of basic igneous rock generally known as trap.

All the rocks of York County are very much jointed, but the joint systems are not so definite and regular as in other parts of Maine. An interesting illustration of the way in which water may enter rock and be held in the fissures is given in Pl. V, *A*. In this locality the



- Successful well over 50 feet in depth
- Unsuccessful well over 50 feet in depth
- Flowing well
- Important spring
- Community having public supply from surface sources
- Community having public supply from wells
- Other important towns

MAP OF YORK COUNTY.

Showing distribution of deep wells, important springs, and communities having public water supplies.

water in the overlying surface deposits will seep slowly downward along the cracks parallel with the stratification and bedding of the slate. Pl. VII, *A*, shows how it may penetrate along vertical joints.

Surface deposits.—The surface deposits of York County range in thickness from less than 5 feet on some of the hills to more than 100 feet in places along the coast and in some of the larger valleys. Over broad areas on the lowlands there are plains of sand and gravel rising to 100 or 200 feet above the sea and increasing in elevation inland. These are generally underlain unconformably by extensive clay deposits, which in this county reach a maximum elevation of more than 100 feet above tide. Generally abundant water is found in the sand and gravel on top of the clay, and this may be of good quality outside the villages. In some places sand and gravel underlie the clay, and water in this material can be found by driving or drilling wells through the clay formation.

WELLS.

GENERAL DESCRIPTION.

Types of wells used.—Most of the wells in York County, as elsewhere in Maine, are of the old open type, ranging in depth from 10 to 50 feet. These are going out of use and are generally not so satisfactory as drilled wells.

Drilled wells.—The drilled wells more than 50 feet in depth are about 70 in number. So far as known, the deepest well in the county is that of Mr. E. S. Marshall at York Harbor, which was drilled to a depth of 325 feet. There are several wells more than 200 feet deep. The most common depth at which sufficient water is found seems to be about 60 feet from the surface, but some wells did not reach the principal vein until they had gone down more than 200 feet. The head varies greatly. In a few wells the water overflows, but in some others it does not stand within 30 feet of the surface.

Quantity of water.—One well at the United States navy-yard at Kittery reports 15 gallons of water a minute, while a neighboring well reports almost no water. The well belonging to the Boston and Maine Railroad at Kennebunk reports 24 gallons a minute. A well at Cape Neddick reports 30 gallons. With these exceptions the supply is 10 gallons or less. Many persons are using water for domestic supplies when the amount is only about a gallon a minute. The water is generally obtained by hand pump or windmill, but a few wells in the summer resorts are pumped by hot-air engines. In some of the summer resorts many excellent wells have been abandoned in recent years, owing to the installation of satisfactory public supplies. Not more than half a dozen deep wells in the county are known to have been entire failures.

Quality of water.—In quality the water runs from very soft to slightly hard. A few wells along the coast have been ruined by the entrance of salt water. The general quality of slate waters in York County may be judged from analyses Nos. 128 to 131. Two of these are complete analyses and report 169 and 209 parts per million of total solids. A field assay of water in till (No. 167), two of water in sand and gravel (Nos. 194 and 195), and one of water in trap (No. 160) have been made. Several analyses of mineral springs are reported (Nos. 285 to 290), recalculated from the owners' figures.

DETAILED DESCRIPTIONS.

Biddeford.—The city of Biddeford, in conjunction with Saco, has a public supply taken from Saco River. The depth of the few drilled wells in Biddeford is about 100 feet, but only a small amount of water has been obtained. The water was found in granite, but is thought inferior in quality to the usual granite water. Several fair wells have been abandoned on account of installation of city water.

Many wells in this vicinity are dug to rock and obtain water in surface deposits overlying it. A few dug and bored wells in the thickly settled portions of the city are 40 feet or more in depth and obtain water in gravel underlying clay. In one well the water rose to the surface and overflowed. A few wells get water at 10 or 15 feet in sand and gravel.

At Biddeford Pool and Fortune Rock there are a number of drilled wells. At Fortune Rock several summer residents pump water by a windmill from a small pond situated a few feet above tide. This pond water is poor and not safe for drinking.

Saco.—Saco, in conjunction with Biddeford, obtains its public supply from Saco River. A number of bored wells in this city obtain water in clay at a depth of 40 to 50 feet, and the supply seems to be excellent for domestic purposes. Some wells get water at 10 or 15 feet in sand and gravel.

Two or more wells in Saco were drilled in clay to a depth of 55 to 60 feet and obtain flows from gravel below 50 feet or more of clay. Ferrys Beach has good driven wells 10 to 15 feet in depth. Saco owns a well 250 feet deep, which supplies water for drinking fountains.

Old Orchard.—Formerly the public supply of Old Orchard Beach was obtained by gravity from Phillip's spring in Saco. At the present time the water of the Saco River is used.

The wells on Old Orchard Beach are mostly driven and bored in sand to an average depth of 15 feet, the deepest being about 40 feet. The water is usually good, but it is sometimes brackish. Away from the shore drilled wells ought to be successful if sunk into the underlying rock.

Buxton.—In the town of Buxton several shallow drilled wells obtain enough water for domestic use. No very deep drilled wells

have been sunk. The village of West Buxton is now having a public supply installed from Saco River.

Kennebunkport.—The villages of Kennebunkport, Ocean Bluff, and Cape Porpoise are furnished with water by the Mousam Water Company, which obtains its supply from Branch Brook, in Kennebunk. The water is of good quality and for that reason there are not many wells in these villages. A few wells from 10 to 40 feet in depth obtain water in sand on top of clay. A large part of the western part of Kennebunkport consists of a plain of clay sloping seaward and overlain and underlain by sand and gravel. Through this plain the rock reaches the surface in places. Most of the wells are dug. A field assay of water from one well dug in clay at North Kennebunkport is given in the table (No. 167).

In the village of Kennebunkport one drilled well was sunk years ago, but is now abandoned and no information regarding it can be obtained. At Ocean Bluff a number of wells were drilled years ago to depths ranging between 40 and 250 feet. As the public supply has now been installed for several years, all wells have been abandoned and no reliable information about them is at hand.

Kennebunk.—The villages of West Kennebunk, Kennebunk, Kennebunk Landing, and Kennebunk Beach, all situated in the same town, obtain their water supply from the Mousam Water Company, which draws it from Branch Brook. Most houses on the line of the aqueduct outside of the villages also use the town water. There are only a few wells in these villages, and all of these are shallow, being dug or driven to depths of 10 to 30 feet. Plenty of water is obtained from them, but the supply is probably not so safe for drinking as the city water. At Kennebunk Beach a well was once drilled to the depth of 80 feet. The dug and driven wells are mostly sunk in sand and gravel, and some of them rest on clay. At the Mineral Spring House at Kennebunk Beach the Kennebunk Beach Mineral Spring is situated.

Wells.—The villages of Wells, Ogunquit, and Wells Beach obtain their public supply, like the villages in Kennebunk and Kennebunkport, from the Mousam Water Company, the source being Branch Brook. The supply is of good quality. In the village of Wells a few dug and driven wells have been sunk, mostly 12 to 15 feet in depth, in sand and gravel. At Crescent Beach a spring from sand supplies eight cottages. The water is pumped by a windmill to a tank.

Only one or two wells have been drilled here. In the southern part of the town a well was once sunk for Mr. A. P. Littlefield and is reported 100 feet deep in granite, obtaining water at about 50 feet. At Ogunquit two or more wells have been drilled, 60 or 70 feet in depth, and obtain several gallons of water a minute. The water of the well belonging to the Charles C. Hoyt estate at Ogunquit has been analyzed, and the composition is given in the table (No. 131).

York.—At York Harbor a well was drilled for the York Harbor Hotel to a depth of 150 feet, but the supply was small and the well is not much used. At York Beach a well was sunk 60 feet deep in granite and obtained a flow which will rise 2 feet above the surface. Two other wells at this place are reported to overflow the surface from depths of 28 and 60 feet. One of these is said to yield 30 gallons a minute by pumping. Several other wells in town obtain supplies at depths of 40 to 90 feet, and the supply is reported to range between 5 and 10 gallons a minute. The well of Mr. E. S. Marshall, at York Harbor is the deepest in York County. It was drilled 325 feet and was "shot," but let in sea water, and for that reason was abandoned.

Several wells drilled in the town of York have met with failure. Three of these were situated at Cape Neddick, only a few hundred yards from one of the good wells mentioned above. One of these failures was drilled to 87 feet, at which depth salt water was encountered, which rose to about sea level. It is worthy of note that two of the unsuccessful wells were drilled in the trap rock which makes up the greater part of Cape Neddick, and that the third was in schist close to the contact with the trap rock, while the successful wells were in slate and schist. A detailed description of the water resources in the vicinity of York has been given by George Otis Smith.[a]

Some water is found at York in and underneath a bed of clay which forms the surface deposit at many places along York River. A small amount seeps out in springs near the bottom of brickyards. One well in a brickyard near York village is dug 18 feet deep in the bottom of a clay pit 8 feet below the surface. The section of this well is as follows: Gray clay, 6 feet; stratified blue clay with thin sand partings, 6 feet; blue clay not stratified, almost quicksand, 6 feet; gravel containing water, 10 feet. A field assay of the water taken from this well is given in the table (No. 195).

Kittery.—Several wells have been drilled on Cutts Island, some at Kittery Point, and several at the navy-yard. At Kittery Point they range from 35 to 60 feet in depth. Mr. Horace Mitchell has five wells from 6 to 60 feet in depth, which together supply the Hotel Champernowne. One of these is drilled 60 feet. The water is pumped from the wells to two cisterns, which together hold 40,000 gallons. In the best season of the summer 200 or more people are supplied by the five wells. The location of two of them is rather poor. It is said that water supplies in slate in this vicinity often give out in dry weather.

The villages of Kittery and Kittery Point are supplied by water from Folly Pond. On Cutts Island there are two drilled wells, one in slate and one in a trap dike. The slate well, owned by Mr. Roland Thaxter, is 75 feet deep; the trap well, belonging to Mr. John Thaxter,

[a] Water resources of the Portsmouth-York region, New Hampshire and Maine: Water-Supply Paper U. S. Geol. Survey No. 145, 1905, pp. 122-127.

is 125 feet. The slate well was "shot" twice with 10 pounds of dynamite, but this did not increase the amount of water. The well in trap a few hundred feet distant was a failure, although it was "shot" four times with 15 pounds of nitroglycerin. Near the same point is a well, a few feet deep, blasted in trap in a cellar. A field assay of this water is given in the table (No. 160). This well seems to be safe from surface drainage, as it is bricked up and cemented to the cement floor of the cellar.

Most of the wells in this town obtain only 20 to 50 gallons of water an hour. The well on the grounds of the Hotel Pocahontas, on Gerrish Island, was drilled in 1895 to a depth of 40 feet, the principal source of water being at 39 feet, with other veins at about 30 feet. The well is reported to yield only about a gallon a minute. The water is raised by a windmill and partly supplies the hotel, although there is another source consisting of a natural spring 7 feet above high tide. This spring has been excavated in rock to the depth of 8 feet and when not pumped overflows through crevices of the rock.

At the navy-yard a well was drilled to a depth of 200 feet, obtaining very little water. A second one was sunk to the same depth with a similar result. The first was then deepened to 300 feet, and 15 gallons a minute were obtained.

The most important well in this vicinity is just over the State line, at the Hotel Wentworth, on Newcastle Island, in Portsmouth, N. H. This well is situated near Forts Constitution and Stark. It was drilled some years ago and is supposed to be about 275 feet deep. During midsummer the steam pump has been run night and day at the rate of 30 gallons a minute for two weeks with no appreciable diminution of the supply. The water is of excellent quality.

Eliot.—In the town of Eliot the wells are all dug. Those in the lowlands sunk in clay to moderate depths get a small amount of water. It is of irregular occurrence and seems to occupy more or less well-defined channels in more sandy strata. At one place a pipe was driven 35 feet through clay, and water was not found, showing that it can not be depended on with certainty.

Berwick.—The public supply of Berwick is derived from two wells in gravel. At least two other wells are said to have been drilled, but are now abandoned on account of the installation of city water. A field assay of this water is given in the table (No. 194).

North Berwick.—In North Berwick one well 125 feet deep, sunk in granite, obtains a few gallons of water a minute near the bottom. One or two other drilled wells have been sunk, but no information regarding them has been obtained.

Lebanon.—At Center Lebanon a well was sunk fifteen years ago to a depth of 50 feet. It yields less than 1 gallon a minute, and contains some iron. The water is used, however, for domestic purposes.

Alfred.—Alfred has no public supply, and the water is obtained chiefly from dug and bored wells, mostly 35 to 50 feet in depth. Plenty of water can be obtained a few feet from the surface. Years ago a drilled well was sunk 140 feet, but for some reason was abandoned. There is no reason why drilled wells will not succeed here.

Sanford.—The village of Sanford is supplied with water from a driven well and a dug well situated on the flood plain of Mousam River, midway between that village and Springvale. The supply is satisfactory. It is described under the appropriate heading (pp. 237–238). There are no wells in use in Sanford village. Springvale, in the same town, is situated 2 miles from Sanford, and is supplied by Littlefields Pond, 1 mile north of the village. The water is called poor and is said to have caused typhoid fever, but the pond is situated on the hills where there should be little danger of contamination. Many dug wells are in use in the village. Formerly there were two small water systems here, one obtaining water from springs in sand and gravel deposits at the lower end of the village, the other using river water. In 1904 the spring company was bought out by the other company, and about that time a typhoid epidemic broke out, which was supposed to have been caused by mixing river water with spring water. The springs issue from the base of a gravel terrace rising 20 feet above them, on top of which and several hundred feet distant some houses are situated, but the water is not supposed to be polluted. The largest spring is reported to flow 45 gallons a minute, and the smaller one 30 gallons. The springs are inclosed in small sheds and the water is collected in tanks. They are still used by a few tenants of the owner. Wells in the town of Sanford are all shallow.

SPRINGS.

General statement.—York County is well supplied with spring water. Most of the people in the country districts use wells, but a few have springs. Within the county are a considerable number of springs the water of which is sold. These are as follows:

Baker Puritan Spring, Old Orchard.
Cold Bowling Spring, Steep Falls.
Indian Hermit Mineral Spring, Wells Village.
Kennebunk Beach Mineral Spring, Kennebunk Beach.
Olde Yorke Spring, Old Orchard.
Seal Rock Spring, Saco.
Wawa Lithia Spring, Ogunquit.
White Sand Spring, Springvale.

Baker Puritan Spring.—In the town of Old Orchard, about 4 miles west from Pine Point in Cumberland County, is a spring owned by I. C. Baker & Co., of Pine Point. It is situated on a high, dry sandy plain from which the water seeps out of a very fine sand. It is color-

less, odorless, tasteless, and very soft. It is reported to flow about 2 gallons a minute, varying slightly in very dry seasons. It is used as a medicinal and table water.

No chemical analysis has been made of this water. A sanitary analysis made in 1895 by H. D. Evans, chemist, reports 2 parts per million of chlorine, 0.2 part of oxygen consumed, 8.1 hardness, 3.5 of soluble organic matter, and 13.5 of residue of evaporation constituting the total solids; nitrites and nitrates are said to be absent.

Cold Bowling Spring.—In the town of Limington, 1 mile south of Steep Falls post-office, is a spring owned by Messrs. George P. and Frank Anderson, of Boston. The spring is known as the Cold Bowling Spring. The water is reported by the owners to issue from gravel overlain by hardpan. The flow is not large, but it is reported not to vary. The surroundings consist of a level wooded plateau. The water is odorless, is exceedingly pleasant to the taste, and is very clear. The temperature is said to be invariable. The water is sold for table and medicinal purposes at 15 cents a gallon. An analysis, recalculated from that of the owners is given in the table (No. 287).

Indian Hermit Mineral Spring.—About three-quarters of a mile east of Wells village is a spring owned by Mr. C. D. Healey, called the Indian Hermit Mineral Spring. The spring is situated on a hillside and the water is said by the owner to issue from ledge with a volume of 5 gallons a minute. The water is colorless and odorless and has a very pleasant taste. It is sold as a table and medicinal water. The water is said to have been analyzed by Rush & Johnstone, chemists, of Philadelphia, who report it to contain lithia, silica, iron, sodium, magnesium, and other elements.

Kennebunk Beach Mineral Spring.—At the Mineral Spring House at Kennebunk Beach there is a spring owned by Mr. H. K. Smith, the water of which has been sold for table use. The spring is said to have been used by the farmers for years. The hotel was built by Mr. W. F. Paul fifteen years ago, being then called the Grove Hill House. The water is used at the hotel for drinking and cooking, and until city water was installed it was used for other purposes. Considerable water is said to be sold to cottages and hotels in the vicinity and in Kennebunk Beach and Kennebunkport. The water is said to have a very peculiar taste. It was analyzed by S. H. Hitchings, chemist, in 1899 and found to contain 189 parts per million of mineral matter. No quantitative determination of the different constituents was made.

The spring is 12 feet across and 2 or 3 feet deep in the center. It is inclosed in a spring house about 15 feet square. The hotel is situated on a ledge on the hillside, 300 feet distant, and 50 feet above the spring. The spring is well walled up and protected by masonry curbing. The water is pumped by a pitcher pump. It is very clear.

The formation is bowlder clay, but hard blue clay outcrops 40 feet distant, across the road. The spring is only 200 feet from the edge of the salt marsh, which may account for the peculiar taste.

Olde Yorke Spring.—The Olde Yorke Spring, owned by the Olde Yorke Springs Company, is situated at Old Orchard. The water is colorless, odorless, tasteless, and excellent for drinking. As shown by the analysis reported in the circular issued by the owners and recomputed as No. 289 in the table, the water contains 94 parts per million of total solids. It is sold at 20 cents a 1-gallon can.

Seal Rock Spring.—In the town of Saco, about 1¼ miles east of the post-office, is the Seal Rock Spring, owned by Mr. M. A. Leavitt. The water is said to boil up from a surface deposit in a valley with a volume of 1½ gallons a minute, which is not supposed to vary with the season. The spring is situated in an open field. The water has no color, odor, or taste, and carries no sediment. No analysis has been made. The water is used for drinking, cooking, and medicinal purposes, and is sold for 5 cents a gallon.

Wawa Lithia Spring.—The Wawa Lithia Spring, owned by Mr. C. W. Dunyon, of Roxbury, Mass., is located 1 mile from Ogunquit, in the town of Wells. The spring is situated in a valley halfway down a hillside, and is said by the owner to issue from a broken granite ledge. It is protected by a small spring house which is kept locked and surrounded by a wire fence. The surroundings are wooded. The water has no color or odor and is very clear. The temperature is low and is said to be variable. The flow is reported to be 1 to 2 gallons a minute with little variation. The water is used for domestic purposes and is sold as a medicinal and table water. The price of a 5-gallon carboy is $1.50. The analysis in the table (No. 288), is recalculated from that given by the company.

White Sand Spring.—The White Sand Spring is situated on a farm near Springvale and the water is sold in Sanford and Springvale. It is owned by Mr. George G. Plummer. The water is reported to issue at the rate of 5 gallons a minute from granite overlain by gravel, on a rather flat slope. It is colorless, odorless, and tasteless, and its temperature varies with the season. It is used for drinking and cooking and is sold in Sanford and Springvale as a medicinal and table water. The total solids reported in an analysis published by the owner are 42 parts per million, and the hardness is 19.5. A sanitary analysis showed practically no nitrates and very little ammonia, which indicates that the water is probably safe for drinking.

PUBLIC SUPPLIES.

General statement.—A number of communities in York County have public supplies, but only two of them are from underground sources. Probably the best water system in the county is owned

by the Mousam Water Company. The supply is taken from Branch Brook, in the town of Kennebunk, and is used by the villages of West Kennebunk, Kennebunk Landing, Kennebunkport, Kennebunk Beach, Cape Porpoise, Ocean Bluff, Wells, and Ogunquit. Kittery and Kittery Point are supplied by Folly Pond. North Berwick and South Berwick use small brooks. York, York Harbor, and York Beach are supplied by the York Shore Water Company from Chase Lake. Biddeford and Saco obtain their water from Saco River. Formerly Old Orchard was supplied from Phillip's spring in Saco, but at present Saco River water is used. Berwick has a well supply. Springvale uses water from Littlefields pond, although formerly the village was supplied by springs. Sanford has a dug well and driven wells near Mousam River between Sanford and Springvale.

Sanford.—The Sanford waterworks consist of 16 driven wells and a large dug well situated on the flood plain beside Mousam River between Sanford and Springvale. The water is pumped into a reservoir and the pressure is derived in part from that and in part from the pumps at the pumping station near by. The water mains consist of galvanized-iron, wrought-iron, and cast-iron pipes, from 12 inches down to 1¼ inches in diameter. It has been thought that the galvanized iron seriously affects the condition of the water, and the pipes sometimes rust through. For that reason the galvanized-iron mains are being replaced by others of cast iron. The capacity of the reservoir is 500,000 gallons and it gives a pressure of 90 pounds.

Until a year ago only the dug well was used, but this water was insufficient and for that reason driven wells were installed. These range in depth from 20 to 30 feet. The water is found in a bed of gravel, which slopes in the same direction as the river, and which is overlain by fine sand and silt; 500 gallons a minute can be pumped for eighteen hours at a stretch. The sand furnishes an excellent natural filter bed, and the supply seems to be perfectly satisfactory.

Berwick.—For five years Berwick has had a supply from driven wells situated on the north edge of the village. The waterworks are owned by the Berwick Water Company. The water is distributed from a reservoir having a capacity of 750,000 gallons and giving a fire pressure of 105 pounds and a regular domestic pressure of 68 pounds. The water is soft and is satisfactory. The mains are about 7 miles in length and there are 30 fire hydrants and 200 taps. About one-tenth of the inhabitants use the public supply. The consumption is 40,000 gallons daily. There is plenty of water and it is reported to be excellent, but persons beyond reach of the mains still use dug wells. A field assay is given in the table (No. 194).

West Newfield.—The people of West Newfield are supplied by a spring, which flows with a volume of 2 gallons a minute. The water is excellent. There are about 1,000 feet of mains and 26 taps.

RECORDS OF DEEP WELLS IN SOUTHERN MAINE.

By W. S. Bayley.

The table on the following pages contains the records of 526 wells more than 50 feet in depth obtained to the date of completing the foregoing report. This list was started by correspondence during the years 1903 to 1905, and was completed and revised by field and office work in 1906 and 1907. An effort has been made to include in it all wells, both successful and unsuccessful, more than 50 feet in depth, which have been sunk in southern Maine. In order to make a systematic canvass of the State, blanks were first mailed to the postmasters, asking for the names of well owners and drillers. The majority of postmasters replied to these inquiries, and to the names obtained in that way another blank was sent, requesting full information regarding the locality, owner, year completed, diameter, type, depth of well, depth to rock, depth to principal and secondary water supplies, head of water, quality of water, yield, use, and method of obtaining water from all wells. Replies were received from about half the persons to whom the inquiries were sent. Where the first request met with no reply, a second was sent.

It is probable that a considerable number of wells have been omitted from the list for the reasons, first, that many well owners did not reply to either the first or the second request for information, and, second, that it has been impracticable on account of expense to visit all the wells in the field. Doubtless there are some dug wells more than 50 feet deep which are not included, as all open wells have been dug many years and it is difficult to obtain reliable information concerning them. Some drilled wells are omitted for similar reasons.

It is believed that most of the information given in the table is correct. In preparing such a table, however, inaccuracies are bound to creep in, and it is probable that there have been some mistakes in filling out the blank forms. The list is especially likely to be somewhat in error with respect to the depths at which water was obtained. Few of the local drillers keep accurate records, and in consequence the only data obtainable regarding depth to water are for the most part such as can be recalled by the well owners. The nature of the rock furnishing the supply is seldom reported in corre-

spondence, and many of the reports made are not reliable, for the reason that persons not educated along these lines are unfamiliar with the correct names of rock formations in which water is found. The data in the column headed "Material" are furnished mainly by F. G. Clapp, G. C. Matson, and B. L. Johnson, who investigated the conditions regarding occurrence of water in southern Maine and who have visited most of the wells listed in the table. In the column headed "Quality of water" the terms "hard" and "soft" will be seen to be of frequent occurrence. In only a few parts of southern Maine are there any really "hard" waters, and for that reason the word must be taken only in a relative sense, as comparing the water with some softer water which is familiar to the person making the report.

The compiler wishes to express his thanks and those of the United States Geological Survey to all persons who have assisted in supplying information. They have done a public service to the community.

Records of deep wells in southern Maine.

[Abbreviations: n. r., no rock; +0, just overflows; −0, reaches surface, but does not overflow.]

No.	Locality.	Owner.	Year completed.	Diameter (inches).	Type.	Depth of well (feet).	Depth to rock (feet).
	Androscoggin County.						
1	Auburn	John Picket			Drilled		0
2	do	Turner Center Creamery	1904	8	do	654	90
3	East Auburn	Frank Merrill	1906		Driven	60	n. r.
4	Lewiston	Bates Mill Co		2½	do	65	n. r.
5	do	W. R. Bartlett	1899	6	Drilled	103½	60
6	do	F. P. Stetson	1891	6		60	
7	Lisbon Falls	Hugh Douglas			Drilled		4
8	do	R. A. Small	1889	6	do	50	10
9	do	Worumbo Woolen Mills			do	187	
10	do	do	1904		do	215	0
11	Livermore Falls	W. A. Thompson			do	65	
12	Mechanic Falls	Portland and Rumford Falls Ry.	1892	6	do	120	15
13	Poland	W. F. Trask and C. F. Gould	1895	6	do	140	
	Cumberland County.						
14	Baldwin	Frank Milliken	1884	2½	Drilled	95½	2
15	Bridgton	A. H. Abbott	1891	6	do	200	35
16	do	Bridgton Aqueduct Co		6	do	290	
16a	do	The Bridgton		6	do	70	
17	do	Rufus Gibbs's heirs		6	do	113	40
18	do	J. K. Martin	1890	6	do	125	20
19	do	Granville Morrison	1903	6	do	72	10
20	do	W. Morrison	1896	6	do	52½	12½
21	do	O. G. Plummer	1890	5½	do	52	10
22	do	G. Whitehouse	1905	6	do	70	30
23	Brunswick	Brunswick and Topsham water district.	1904	2½	Driven	25–35	n. r.
24	Cape Elizabeth	Geo. G. Brooks		6	Drilled	75	0
25	do	J. B. Coyle estate		6	do	80	
26	do	Geo. T. Cruft	1899	6,5	do	127	3
27	do	James Cunningham			do	50	4
28	do	Mrs. E. Dennison	1906	6	do	60	0
29	do	—— Goodrich		6	do	55	
30	do	Amos Miller	1894	6	do	115	2
31	do	Geo. F. Morse			do	60	0
32	do	N. W. Morse	1895	6	do	75	0
33	do	Shore Acres Land Co		6	do	151½	3
34	do	U. S. Government (light-house).	1902	6	do	149	1
35	Clapboard Island, Falmouth.	S. F. Houston	1899	6	do	210	6
36	Cow Island	U. S. Government	1905	6	do	390	
37	Cushing Island	Francis Cushing			do	275	40
38	do	S. W. Thaxter et al	1889	6	do	70	10
39	do	do	1892	8.6	do	80	2
40	do	U. S. Government (Fort Levitt).	1902		do	550	
41	do	do	1905	8	do	326	11
42	do	do	1906	8	do	277	18
43	do	do	1907	8	do	482	15
44	East Otisfield	Lester Jilson	1888	7	do	68	62
45	Falmouth	J. M. Brown	1897	6	do	205	
46	do	E. H. Ingalls	1894	6	do	149¾	12
47	do	George Woodward	1900	8	do	200	
48	Freeport	Clark grist mill	1886	6	do	140?	30
49	do	Freeport Granite Co	1886	6	do	160?	40
50	do	Mrs. C. H. Mallett	1888	6	do	180?	
51	do	O. W. Shaw & Co	1886	6	do	140?	40
52	Gorham	J. H. Carroll	1894	8	do	92	76
53	do	Dan. Cressey	1897	8	do	66	5
54	do	A. B. Deering	1906	6	do	80	5
55	do	Gorham Normal School	1892	6	do	96	0
56	do	Melville Johnson	1902	6	do	90	68
57	do	Clarence McMakin			do	80	few
58	do	H. L. Martin	1900	6	do	60	17
59	do	J. H. Rines	1900	6	do	307	0
60	do	Fred Smith	1901	8	do	105	19
61	do	Wm. E. Strout	1895	8,6	do	65	6

Records of deep wells in southern Maine.

[Abbreviations: n. r., no rock; +0, just overflows; −0, reaches surface, but does not overflow.]

Depth to principal water supply (feet).	Depth to other supplies (feet).	Material in which water occurs.	Average height to which water rises (+ above, − below, well mouth).	Quality.	Yield (gallons per minute).	How obtained, where used.	Use, or if not used, the reason why.	No.
		Gneiss				Abandoned		1
		do			0	Not used	No water	2
		Gravel	+ 0	Fair			Drinking	3
63		do		Iron and magnesia.		Steam pump	Bleaching	4
	60	Gneiss		Good	3	Not used	Too little water	5
50			− 20	Hard, iron		Pump	Domestic	6
		Granite						7
47		do	− 15	Hard	2	Hand pump	Domestic	8
		do	few	Sulphur				9
63		Gneiss			35			10
		Granite						11
		do	− 10	Soft		Not used	Too little water	12
135		do	+ 0	Hard	18	do		13
			− 17	Soft		Windmill	Domestic	14
198		Granite	− 12	do	90	do	Domestic and irrigation.	15
		do				Never used	Very little water	16
		do		Good		Abandoned	Water works installed.	16a
		do		do	6	do	Not enough for hotel	17
115		do	− 75	Soft	20	Hand pump	Domestic and stock	18
		do	− 10	do	many	Windmill	Domestic	19
45		do	− 12	do	6	do	Domestic and stock	20
		do	− 30	Hard		Pump	do	21
70		do	− 47	Soft	5	Windmill	do	22
3–10		Sand	−1 to + 0	Hard		Steam pump	Public supply	23
		Schist		Brackish		Abandoned	City water installed	24
		do						25
75	60		− 27	Hard		Windmill	Domestic and stock	26
				Good	many		Domestic	27
		Schist		Hard		Hand pump	do	28
								29
115	90	Schist	− 6	Hard	few	Windmill	Domestic	30
		do						31
		do	− 5	Hard		Windmill	Domestic	32
		Slate	− 30	Good	many	do	Domestic and stock	33
140	60		− 6	Alkaline	32	do	Drinking and stock	34
200	60		− 35	Good		Hot-air engine	Domestic and stock	35
			+ 0		20			36
		Gneiss				Steam pump	Public supply	37
		Schist	− 50	Fair	10	Windmill	Domestic	38
		Gneiss	− 25	Good		do	do	39
		Schist				Not used	Water gave out	40
280	60, 45	do	− 20	Good	10		Supply of fort	41
		do	− 20	Iron	30	Steam pump	do	42
180	464	do	− 18		5		do	43
				Hard		Windmill	Domestic and stock	44
204				Soft	40	do	Domestic	45
				Hard		do	do	46
200	50		− 6			Pump	do	47
			− 40			Not used	City water installed	48
			− 40			do	do	49
160			− 5					50
			− 50			Not used	City water installed	51
92		Slate	− 75			Windmill	Domestic	52
66	few	do	− 4	Hard		Hand pump	do	53
60	80	do	− 30	Good		Pump	Domestic and stock	54
92			+ 1	Hard		Not used		55
85		Slate	− 40		1½	Windmill	Domestic and stock	56
		Schist		Little hard			Domestic	57
		Slate	− 14	Hard	5	Windmill	Farm	58
	30	do	− 30	do		do	Domestic and stock	59
		do	− 18	Soft		do	Domestic	60
63		Schist	− 9	Hard		Hand pump	Domestic and stock	61

Records of deep wells in southern Maine—Continued.

No.	Locality.	Owner.	Year completed.	Diameter (inches).	Type.	Depth of well (feet).	Depth to rock (feet).
	Cumberland County Continued.						
62	Great Chebeague Island.	Ellis Ames Ballard		6	Drilled	301	
63	Great Diamond Island	Diamond Island Association	1893	6	do	120	8
64	do	do		6	do	90	6
65	do	W. A. Stone	1900	6	do	215	6
66	do	U. S. Government (Fort McKinley).			do	302	
67	do	do	1902	6	do	97½	10
68	do	do	1902	6	do	265½	
69	do	do	1902	6	do	95	8
70	do		1899	6	do	265	16
71	Harrison	Dan Caswell			do	65	20
72	do	Ben Harmon			do	90	
73	House Island, Portland.	U. S. Government (quarantine).			do	270	0
74	Little Chebeague Island.	J. H. Hamlin			do	197	100+
75	Little Diamond Island	U. S. Government (light-house).	1902	8	do	171	6
76	Mere Point	W. D. Pennell		6	do	67	0
77	Naples	Mrs. A. F. Perly	1895	8	do	210	13
78	New Gloucester	Shaker Society	1895	6	do	150	
79	Otisfield	Lester Jilson			do	100+	
80	Peaks Island	Beacon Hill Water Co.		6	do	93	0
81	do	Sue Cole		6	do	75	
82	do	Tom Frothingham, jr	1899	6	do	90	0
83	do	C. W. T. Goding	1900	8	do	135	
84	do	Hillburn estate			do	60	14
85	do	Peaks Island Water and Light Co	1898	8	do	202	0
86	do	do	1905	8	do	203	0
86a	do	do	1907	8	do	201	2
87	do	Harriet M. Skillings's heirs			do	80	
88	do	J. H. Tolman	1896	8, 6	do	97	3
89	Portland	Jas. P. Baxter	1895	6	do	164	0
90	do	Chas. A. Brown				60	
91	do	Burgess-Forbes & Co	1887	6	Drilled	298½	149½
92	do	E. T. Burrows & Co	1891	6	do	106	5
93	do	Consolidated Electric Light Co. of Maine.	1887	8	do	204	8
94	do	D. F. Emory	1906	6	do	128	42
95	do	Foster's dye house	1886	6	do	140	0
96	do	Mary J. Frazer		6	do	210	
97	do	M. R. Griffith	1897		do	178	30
98	do	Maine General Hospital	1892	6	do	505	100+
99	do	do	1901	10, 8	do	830	97
100	do	John T. Palmer	1897		do	164	4
101	do	Y. M. C. A. building	1898	9	do	96	0
102	Scarboro	Walter Briggs			Dug	56	
103	do	Ira C. Foss		6	Drilled	290	
104	do	H. J. Libby estate	1905	7	do	201	19
105	do	S. D. Plummer		8	do	127	1
106	Sebago Lake	Chas. Dolloff heirs	1895	6	do	60	
107	South Freeport	G. A. Dixon	1888	6	do	100	6
108	do	J. H. Leo	1901	6	do	108	0
109	South Windham	J. L. Robinson	1902	6	do	121	41
110	Standish	Jno. W. Bowers	1902	6	do	60	12
111	do	Mrs. G. W. Granville	1901	6	do	60	50
112	do	Almond Marean	1897	6	do	63	
113	do	Frank H. Rand	1900	6	do	78	8
114	do	R. W. E. Shaw	1897	6	do	86	
115	Westbrook	Haskell Silk Co	1904	6	do	216	6
116	do	do	1904	6	do	200	0
117	do	Rufus Jordon	1903	6	do	216	
	Franklin County.						
118	Farmington	Warren Ladd	1850		Dug	58	
119	North Jay	Leon H. Look	1903	2	Driven	70	n. r.

Records of deep wells in southern Maine—Continued.

Depth to principal water supply (feet).	Depth to other supplies (feet).	Material in which water occurs.	Average height to which water rises (+ above, − below, well mouth).	Quality.	Yield (gallons per minute).	How obtained, where used.	Use, or if not used, the reason why.	No.
55		Schist	− 15	Good	½	Windmill	Domestic	62
		Slate	+ 0	Hard	12	Hot-air engine	Public supply	63
		do	− 15	do	15	do	do	64
		do	+ 0	Soft	8	Steam pump	Domestic	65
		Schist	− 20		14			66
80		Slate	+ 0	Hard	25			67
100		do	− 3	do	15	Not used		68
80		do	+ 0	do	30			69
35		do	− 8	Soft	60	Steam pump	Domestic	70
		Granite		Good				71
		do				Abandoned	House burned	72
		Schist			15	Windmill	Domestic	73
		do				Not used	Water gave out	74
160		Slate	− 6	Salty	4	do	Water too salty	75
		Schist				Hand pump	Domestic	76
			− 24		¾	Steam pump	Stock and irrigation	77
35			− 35		¼	Not used		78
		Granite						79
23		Schist	− 10		25	Hot-air engine	Public supply	80
		do		Hard, little iron.	few	Hand pump	Domestic	81
90		do	− 10	Little iron	5	do	Domestic and stock	82
		do	+ 0		52	Steam pump	Boilers and hotel	83
60		do			many	Hand pump	Domestic	84
		do		Hard	85	Steam pump	Public supply	85
193		do	− 28	do		do	do	86
140	90	do	− 30	do		do	do	86a
		do				Hand pump		87
84		do		Soft	2	Windmill	Domestic	88
164		Slate	− ½	Hard			Business block	89
60		do	− 10	Soft				90
160	288	do	−160	Soft, alkaline.	14	Steam pump	Boilers and drinking	91
106		do	− 15	Hard		do	Fire service and washing.	92
136	29	do	− 9	Salty	65	Not used	Water too salty	93
120		do	− 42	Soft	1¼	Windmill		94
60		do	− 12	do	30	Pump	Dye house	95
		do	+ 0	do	25	Windmill	Supplies many tenements.	96
		do	− 78	Hard				97
405	505	do	−100	Soft	13	Steam pump	Domestic and boilers	98
97		Gravel	−100	do	3	Not used	Too little water	99
		Slate		Hard				100
38		do		do	26	Abandoned	Sometimes brackish	101
			− 54			Windmill	Domestic	102
275				Salty		Not used	Water salty	103
200	40	Slate	− 14	Hard	8	Windmill	Domestic and stock	104
		do	− 8	do	many	do	do	105
			− 10	Soft			do	106
	15		− 4	Medium		Hand pump	Domestic and factory	107
	35	Granite	− 18	Hard	½	Windmill	Domestic	108
		Slate	− 40	Muddy	5	Not used	Poor water	109
59			− 15	Soft		Hand pump	Domestic	110
60		Schist	− 4	do	4	do	do	111
13			− 13	Hard		do	do	112
71	50	Schist	− 4	Soft	9	do	Domestic and stock	113
		do	− 26	Hard	3	do	Farm	114
200	50	Slate and granite.	+ 0	Hard, sulphur.	34	Air lift	Manufacturing	115
200	50	Slate	− 16	do		do	do	116
216		do	+ 8	Hard	2	Natural flow	Domestic	117
58		Clay				Windlass	Domestic	118
						Not used	Too little water	119

Records of deep wells in southern Maine—Continued.

No.	Locality.	Owner.	Year completed.	Diameter (inches).	Type.	Depth of well (feet).	Depth to rock (feet).
	Hancock County.						
120	Bar Harbor	Edw. Morrell	1902	6	Drilled	87½	2
121	Black Island	Brown & McAllister	1893	6	do	74	4
122	Bluehill	A. M. Thomas	1905		do	140	20
123	do	A. S. Thomas			do	208	
124	Bluehill Falls	Mrs. Ethelbert Nevins	1905		do	90	
125	Brooklin	Brooklin Packing Co		6	do		
126	do	Wm. W. Dodge		6	do	112	2
127	do	G. S Stevens	1888	5	do	104	
128	do	Noah V. Tibbetts	1904	4	do	87	4
129	do	Mrs. Wilson			do	55	
130	Bucksport	Melville Chapman	1891	6	do	80	few
131	do	Eastern Maine Conference Seminary.	1902	6	do	308	0
132	Castine	Acadian Hotel Co	1906	6	do	368	43
133	do	Castine Water Co	1893	7	do	58	14
134	do	do	1893	7	do	70	14
135	do	do	1894	8	do	80	14
136	do	do	1896	7	do	110	14
137	do	do	1899	8	do	675	12
138	do	Geo. W. Perkins	1893	7	do	50	7
139	Crotch Island, Stonington.	Ryan-Parker Construction Co	1906		do	303	
140	East Orland	Tom Mason		6	Driven	87½	n. r.
141	Great Cranberry Island	Moorefield Storey	1904	6	Drilled	207	9
142	do	do	1907		do	250	
143	Greening Island	Colton	1903		do	110	
144	do	J. G. Thorp	1896	6	do	90½	2
145	Hancock	Hancock Water, Gas and Power Co.	1880	100	Old mine shaft.	98	4
146	do	D. H. Saunders	1888	6	Drilled	65	5
147	do	E. L. Stratton	1904	6	do	50	12±
148	do	Jeremiah Stratton	1905	6	do	65	4
149	do	Town of Hancock	1902	2	Bored	30	n. r.
150	Isle au Haut	Mrs. R. A. Sturtevant	1895	6	Drilled	78	0
151	Little Cranberry Island	Miss Frothingham	1903	6	do	50	0
152	Mount Desert Ferry	F. L. Colby	1888	6	do	60	5
153	do	I. G. Crabtree	1888	6	do	65	
154	North Sullivan	C. H. Abbot	1903	6	do	37	3
155	do	Crabtree & Havey	1902	6	do	51	0
156	Northeast Harbor	L. E. Kimball	1900	6	do	189	0
156a	do	J. G. Thorp	1896	6	do	90	7
157	Orland	A. H. Dresser	1899	6	do	43	
158	do	A. W. Emerson	1890	6	do	42	2
159	do	Mrs. A. W. Hutchins		6	do	77	12
160	do	A. J. Jordan	1887	6	do	65	4
161	Otter Creek	Mrs. Birge	1899	6	do	37	4
162	Sorrento	Frank Jones estate	1896	2	Driven	[a]50–60	n. r.
163	do	do	1891	6	Drilled	92	4
164	do	Isaac Lawrence		6	do	114	
165	do	William Lawrence	1892	7	do	61	0
166	Southwest Harbor	Southwest Harbor Water Co	1891	6	do	136	
167	do	do	1895	6	do	125	
168	do	do	1899	5¾	do	297	6
169	Stonington	Geyer & Torey	1900	5¾	do	144	2
170	do	Samuel Goss	1893	5½	do	67½	2½
171	do	Pine Lake Water Co	1896	6	do	183	0
172	do	J. C. Rogers & Co	1906	6	do	94	0
173	do	do	1908	6	do	279	0
174	Sullivan	Dwight Braman	1889	10	do	98	0
175	do	do			Blasted and drilled.	120	0
176	do	S. V. Bennis		6.5	Drilled	108	30
177	Suttons Island	Wm. Burnham	1902	6	do	199	6

[a] 14 wells.

Records of deep wells in southern Maine—Continued.

Depth to principal water supply (feet).	Depth to other supplies (feet).	Material in which water occurs.	Average height to which water rises (+ above, − below, well mouth).	Quality.	Yield (gallons per minute).	How obtained, where used.	Use, or if not used, the reason why.	No.
87½		Granite		Good		Hand pump	Stock	120
70	50	do	− 3	Iron	15	do	Domestic and quarry supply.	121
		Gneiss	− 0	Soft, muddy	many	Hot-air engine	Stock	122
		do		Iron		Hand pump	Domestic	123
		do			7½	Hot-air pump	do	124
		Granite			many		Sardine factory	125
		do	− 26	Good		Windmill	Domestic	126
103	20, 40		− 20		2½	Pump	Domestic and boiler	127
87	20, 60		− 0	Soft	many	Steam pump	Domestic	128
		Granite		Good		Hand pump		129
70	20	Quartzite	− 20	Iron	few	do	Domestic	130
100	300±	Slate	− 8	Hard, iron	many	Gasoline engine	Washing and boilers	131
278		Volcanic tuff	− 15	Hard	10	Hot-air engine	Hotel	132
		do				Not used	Drill stuck	133
62		do	− 25	Soft	27	Windmill and steam pump.	Public supply	134
62		do	− 25	do		do	do	135
62		do	− 25	do		do	do	136
620		do	− 27	do	13	Windmill	Little used	137
48	40		− 8	do			Dairy	138
		Granite		Salty		Not used	Water salty	139
		Sand	− 40	Good	8	Windmill	Domestic and stock	140
		Felsite			1	Not used	Too little water	141
		do			few			142
90				Salty		Not used	Water salty	143
86	45	Granite	− 9	Soft		Windmill	Domestic	144
			− 3	Little hard		Windmill and gasoline engine.	Public supply	145
62			− 12	Soft	few	Hand pump	Stock	146
30	50	Schist	− 20		many		Domestic	147
50		do	− 45	Little hard			do	148
30		Gravel	+ 5	Soft	½	Natural flow	Drinking fountain	149
72	30		− 4	do	10	Windmill and gasoline engine.	Domestic and stock	150
50			− 6		5	Hand pump	Domestic	151
60			− 30			do	do	152
10			− 10	Soft		Pump	do	153
37		Granite		Good	16	Hand pump	do	154
18		do	− 10	Little iron	many	do	do	155
180			− 83	do	40	Not used	City water installed	156
86	30		− 7	Soft	10	Windmill and gasoline engine.	Domestic and irrigation.	156a
23		Slate	− 20	Hard		Hand pump	House unoccupied	157
42		do	− 20	Hard, good		do	Domestic	158
67			− 59	Iron		do	do	159
60	33, 44	Slate	− 7	Iron, muddy		Not used	Poor water	160
34		Granite	− 3	Good		Hand pump	Domestic	161
50–60		Sand	+ 0	do		Abandoned	Formerly village supply.	162
90		Slate	− 11	Soft	6	Not used	Brackish	163
								164
56		Slate	− 14	Soft	4	Not used	Brackish	165
120		Granite	− 80	Hard	50	do		166
95		do	− 9	Soft	45	Gasoline engine and windmill.	Public supply	167
		do	− 30	Medium	100	do	do	168
144		do	− 7	Soft	1½	Windmill	Domestic	169
65	35	do	− 7	Hard	3	Windmill and gasoline engine.	Supplies 15 families	170
180		do	− 18	Soft	28	Not used	Never connected	171
45	38	do	− 4	Good	60	Steam pump	Quarrying	172
210		do				do	do	173
		do	− 8			Hand pump and windmill.	Drinking	174
		do						175
		Slate				Not used	Too little water	176
199	174	Trap	− 6	Soft	20	Gasoline engine	Domestic	177

Records of deep wells in southern Maine—Continued.

No.	Locality.	Owner.	Year completed.	Diameter (inches).	Type.	Depth of well (feet).	Depth to rock (feet).
	Hancock County—Con.						
178	Suttons Island	Church & Burnham		5½	Drilled	90	
179	Trenton	Geo. J. Safford	1904	6	do	54	22
180	Washington Junction	H. B. Phillips				130±	
181	West Sullivan	J. Clapham	1889	6	Drilled	61	20
182	do	V. B. Gordon			Old mine shaft.	410	
	Kennebec County.						
183	Albion	A. S. Besse	1876	7		45	
184	Augusta	G. P. Sanborn	1898	6	Drilled	560	0
185	Farmingdale	H. M. Hodgdon	1889	6	do	108	3
186	do	Tibbetts & Sawyer	1889	6	do	80	2
187	do	Charles Trask	1889	6	do	56	39
188	Gardiner	Chas. Hopkins	1890	6	do	34	5
189	Hallowell	H. G. Vaughan	1880	6	do	70	20
190	Litchfield	Harlan P. King	1891		do	77	10
191	Pittston	C. C. Libbie	1890		do	56	10
192	do	B. E. Moody		5	do	100	
193	do	do		5	do	85	
194	do	L. E. Moody	1890	5¾	do	135	4
195	Sidney	J. J. Frye	1886		do	230	
196	do	G. F. Bowman	1902	6	do	92	66
197	Vassalboro	American Woolen Co	1902		do	50	
198	Winslow	J. L. Dean	1904	6	do	65	5
199	do	Hollingsworth & Whitney Co.[a]	1899	6	do	110–125	
200	do	do	1901	6	do	67	5
201	do	Ralph Simpson	1904	6	do	55	5
202	do	J. P. Taylor	1880	5	do	65	9
203	do	Chas. Withie	1904	6	do	55	5±
204	Winthrop	C. M. Bailey Sons & Co	1906	6	do	307½	36
205	do	C. H. Gale	1895	6	do	87	0
206	do	do			do	96	
207	do	do			do	65	
208	do	do	1899	6	do	120	50
209	do	H. P. Hood & Son	1903	8	do	172	18
210	do	Frank S. Wood	1905	8	do	176	2
211	Winthrop Center	C. I. Bailey and J. Briggs	1890	5¾	do	200	9
212	do	C. M. Bailey	1893	5¾	do	184	12
213	do	E. A. Bailey	1889	5	do	113	4
214	do	Mrs. Hannah J. Bailey	1898	6	do	200	
	Knox County.						
215	Appleton	F. J. Oakes	1900	6	do	320	
216	Crescent Beach	F. M. Smith	1906	6	do	75	1
217	High Island	W. Gray & Sons	1905	6	do	230	
218	North Haven	H. W. Chaplin	1891	6	do	200±	0
219	do	W. A. Gaston			do	57	
220	do	Lewis Herzog	1905	6	do	164	
221	do	Henry Jackson	1904		do	150	
222	do	F. S. Mead	1896		do	126	0
223	do	Nelson Mullen	1893	6	do	121	6
224	do	Chas. S. Rackeman			do	165	
225	do	F. H. Smith	1893	6	do	118	3½
226	do	C. S. Staples and J. M. Howe	1902	6	do	300	
227	do	do	1902	6	do	200	0
228	do	C. G. Wells	1903	5¾	do	282	2
229	do	do	1895	6¼	do	142	2½
230	do	do	1894	6	do	122	3½
231	Rockland	Rockland Machine Co	1900	6	do	97	
232	Rockland Breakwater	Rieker Hotel Co. (Hotel Samoset)	1906	8	do	640	14
233	Tenants Harbor	J. B. Aldrich	1894	5½	do	54	
234	do	Wm. S. Richardson	1894	6	do	67	10

[a] 7 wells along a 90-foot line.

Records of deep wells in southern Maine—Continued.

Depth to principal water supply (feet).	Depth to other supplies (feet).	Material in which water occurs.	Average height to which water rises (+ above, − below, well mouth).	Quality.	Yield (gallons per minute).	How obtained, where used.	Use, or if not used, the reason why.	No.
85			− 9	Sulphur	14	Not used		178
			− 10	Good	20	Hand pump	Domestic and stock	179
								180
40	61		− 8	Mineral	5	Not used	Bad taste	181
						Siphon	Boilers	182
25	10		− 35	Hard		Windmill	Domestic	183
180		Granite	−400	Soft	few	do	Irrigation	184
104		Slate	− 7	do	5	Pump	Domestic and stock	185
75		do	− 9	do	5½	Hand pump	Milk farm	186
53		do	− 9	do	20	do	Domestic and stock	187
25		Schist		Medium	many	Windmill	do	188
70	20	Slate	− 15	Hard		Not used	Poor water	189
50	30	do				Pump	Domestic	190
53			− 9	Soft	10	Hand pump	Domestic and stock	191
10			− 4			Not used	Drilled for ore	192
						do	do	193
132	77		− 9	Soft	8	Hand pump	Domestic and stock	194
230		Slate						195
70		do	− 30	Soft	1½	Windmill	Domestic	196
			− 14				do	197
		Slate	− 27	Little hard	60	Hand pump	Domestic and irrigation.	198
		do	− 7			Air lift	Cooling acid, but now abandoned.	199
63		do	− 8			Hand pump	Drinking	200
		do						201
		do		Hard, iron	15	Hand pump	Drinking and stock	202
		do			few			203
300		Schist	− 9	Good	50	Steam pump	Boilers	204
25		do	− 12			Windmill	Public supply	205
		do		Good		do	do	206
		do		do		do	do	207
		do	− 20	Hard	many	Siphon	do	208
100		do	− 7	Good	25	Steam pump	Creamery	209
	100	do	− 20	do	4	Electric pump	Domestic	210
	195	do	− 7	do	20	Windmill	Domestic and stock	211
183		do	− 27	do	30	Steam pump	Boilers	212
112	15	do	− 3		12	Windmill	Domestic and stock	213
		do	− 50	Good	15	do	do	214
60			− 10	Soft	15	Not used		215
		Complex	− 2	Variable	6	Windmill and gasoline engine.	Public supply	216
		do			72			217
175			− 25	Little hard	½	Windmill	Domestic	218
								219
				Poor	3½	Abandoned	Ruined by accident	220
				Soft		Gasoline engine.	Domestic	221
125		Trap		Hard	10	Windmill	do	222
118	67	do	− 7	Little iron	4½		Hotel and 5 cottages	223
		do		Good				224
116				Soft	4	Windmill	Domestic and stock	225
					dry	Not used	No water	226
64			− 14	Hard	½	do	Too little water	227
68			− 35	Medium	6	Windmill	Domestic	228
140			− 9	Hard	20	Windmill and hot-air engine.	Cottage and yachts	229
112			− 9	Salty	2½	Windmill	do	230
90			− 20	Soft	40	Not used	Too salty	231
185					10	do	Too little water for hotel.	232
50		Gneiss	− 12	Soft		Windmill	Domestic	233
66		do	20	Hard	2	do	do	234

Records of deep wells in southern Maine—Continued.

No.	Locality.	Owner.	Year completed.	Diameter (inches).	Type.	Depth of well (feet).	Depth to rock (feet).
	Knox County—Cont'd.						
235	Thomaston	Thomaston Brick Co.			Drilled	386	
236	Vinalhaven	Bodwell Granite Co.	1880	6	do	125	
237	do	Wm. B. Clark and others	1903		do	220	6
238	do	H. L. Fransis		6	do	185	12
239	do	J. M. Howe	1897	5⅝	do	120	2½
240	do	Sanborn, Glidden and Raymond.	1904	4	do	203	0
241	do	Alex. Strong	1897	5⅞	do	181	5
242	do	Vinal Haven Fish Co.	1903	6	do	225	0
243	do	G. W. Wheelwright	1899	6	do	180	0
244	Warren	Warren Water Co.	1903	6	do	196	4
245	Washington	A. E. Poland	1905	6	do	95	5
246	West Rockport	Oscar Gould	1885	6	do	50	3
247	Widows Island	Maine Insane Hospital	1906	6	do	109	6
	Lincoln County.						
248	Birch Island, South Bristol.	E. A. Means	1901	6	Drilled	75	3
249	Bristol	H. E. Cotton	1905	6	do	70½	4
250	Bristol Mills	J. W. P. Goudy	1905	6	do	52	12
251	do	J. C. Hyson	1906	6	do	62½	18
252	Cooper Mills	Chas. H. Ashford	1896±	6	do	65	
252a	Christmas Cove	D. Y. Comstock				40	
253	do	G. K. Dennett	1902	6	Drilled	50	0
254	do	T. O. Little & Son	1902	6	do	130	16
255	do	W. E. Little	1902	6	do	106	22
256	do	A. T. Thorpe	1901	6	do	123½	0
257	do	A. S. Warner	1903	6	do	83	0
258	do	Everett Westcott	1902	6	do	160	0
259	do	E. F. Wilder	1902	6	do	55	
260	Damariscotta	Mrs. G. C. Chapman	1902	4	do	87½	25
261	Damariscotta Mills	G. W. Waltz	1905	6	do	50	12
262	East Boothbay	Ammonia Works	1891	5	do	157	10
263	do	do	1891	6	do	154	
264	do	Fred Curtis	1905	6	do	84	
265	do	Hodgdon Bros.	1904	6	do	120	2
266	do	Captain Race	1904	6	do	51	
267	do	Frank Rice	1904	6	do	72½	2
268	do	Frank L. Weston	1904	6	do	72	0
269	Hodgdons Island, Bristol.	Stratton	1905	6	do	118½	3
270	Inner Heron Island	Wm. C. Damon	1904	6	do	119	0
271	do	Heron Island Co.	1890	6	do	62½	10
272	Jefferson	Abram Braun	1884	6	do	91	
273	do	L. R. Hodgkins	1880	6	do	119	0
274	Linekin Neck	F. C. Lowden	1901	6½	do	250	0
275	do	John A. Royal	1904	6	do	95	0
276	Newcastle	J. M. Glidden	1892	5	do	85	12
277	do	W. T. Glidden	1892	5½	do	88½	9
278	do	S. D. Wyman	1902	6	do	76	
279	New Harbor	E. W. Fossett	1901	6	do	33	
280	do	F. A. Fossett	1901	6	do	140	3
281	do	C. T. Poland		6	do	33	
282	North Boothbay	Paul Conklin	1904	6	do	142½	
283	North Edgecomb	F. R. Curtis	1905	4	do	84	0
284	North Whitefield	John Dowden	1889	6	do	105	35
285	do	A. R. G. Smith	1889	6.5	do	114	9
286	Ocean Point	L. J. Crooker	1903	6	do	360	0
287	do	Emerson	1904	6	do	67½	
288	Pemaquid Beach	C. A. Sproul	1901	6	do	42	3
289	Pemaquid Point	Chamberlain & Elliott	1900	6	do	55	0
290	do	W. A. Elliott	1901	6	do	51	0
291	South Bristol	N. W. Gamage	1902	6	do	102	
292	South Newcastle	Mrs. C. A. McMichael	1901	6	do	56	10
293	Squirrel Island	K. H. Richards			do	200	0
294	Waldoboro	R. L. Benner	1902	6	do	41	2

Records of deep wells in southern Maine—Continued.

Depth to principal water supply (feet).	Depth to other supplies (feet).	Material in which water occurs.	Average height to which water rises (+ above, − below, well mouth).	Quality	Yield (gallons per minute).	How obtained, where used.	Use, or if not used, the reason why.	No.
		Limestone		Hard	4			235
50		Granite	− 3	do		Gasoline engine	Granite dressing	236
		do		Brackish		Pump	Washing	237
180			−14		10	Windmill	Cottage and yacht	238
115		Trap	−10	Medium	22	do	4 cottages	239
60		Granite	−27	Hard	⅜	Hand pump	Domestic	240
175		Trap	− 7	Soft	25		do	241
215	50, 75	Granite	−30	Alkaline	20	Gasoline engine	Canning factory	242
		Trap	−15	Hard	5	Windmill	Domestic and stock	243
165			+ 5	Soft	100	Windmill and gasoline engine.	Public supply	244
95	40	Complex	−22		8	Hand pump		245
27		do		Soft		do	Domestic and stock	246
70	40, 100		− 5	Hard	3	Gasoline engine	Domestic	247
73	30	Complex	−12	Soft	2	Hand pump	Domestic	248
		do	−30		1		do	249
52	35	do	−15	Good	1	Hand pump	do	250
50		do	− 9	Iron	5	do	Domestic and stock	251
		Gneiss		do		do	Drinking	252
		Complex						252a
50	35	do	−40	Hard	1½	Hand pump	Domestic	253
128	60	do	− 6	Soft	12	Windmill	Summer hotel	254
86	50	do	−20	do	2	do	do	255
94		do	− 8	Good		Not used	Hotel burned	256
		do	−52	Hard, good		Windmill	Domestic	257
92	40	do	−25	Soft		Hot-air pump	do	258
		do	− 5	Good	many	Hand pump	do	259
57		do	−14	do	1½	Windmill	Domestic and stock	260
47		Granite	−14	Soft	many	Hand pump	Domestic	261
56		Complex	− 6	Mineral	3½	Not used	Works abandoned	262, 263
							Domestic	264
47		Granite	− 3	Good	many	Hand pump	do	265
							do	266
75	34	Granite	−35	Hard	many	Hand pump	do	267
65		do		Good	many	do	do	268
117		Complex	− 6		5			269
115	85	do	− 4	Iron	many	Hand pump	Domestic	270
60		do	−60	do		Windmill	do	271
25		do		do		Hand pump	do	272
			− 3½	do		do	do	273
248	33, 83		−30	Soft	10	Steam pump	do	274
85		Schist		Good		Hot-air engine	Domestic and stock	275
85		Complex	−11	Soft	7	do	Domestic, stock and irrigation.	276
84		do	−34	Medium	7	do	Domestic	277
40		do	−15	Hard	many	Hand pump	Farm	278
		do	− 6	Iron		do		279
134	16, 85	do	−16	Hard		do	Domestic and stock	280
		do	− 5	Iron				281
								282
84			−20	Hard	8	Hand pump	Domestic	283
90	30		−39	Soft	9	do	Domestic and stock	284
114	39, 77	Complex	− 4	do	21	do	Domestic	285
		do	−15	Good	10	Windmill and gasoline engine.	7 cottages	286
		do					Domestic	287
30	12	do	− 6	Salty	½	Hand pump	Stock	288
		do	− 4			do	Domestic	289
50	20	Granite	− 4		many	do	Hotel	290
100	36	Complex	−65	Hard, iron		do	Domestic	291
56		do	− 1	Soft	3½	Abandoned		292
40		Granite			½	Not used	Too little water	293
38		do	− 3	Hard		Hand pump	Domestic	294

Records of deep wells in southern Maine—Continued.

No.	Locality.	Owner.	Year completed.	Diameter (inches).	Type.	Depth of well (feet).	Depth to rock (feet).
	Lincoln County—Cont'd.						
295	Waldoboro	E. F. Genthner	1902	6	Drilled	56	4
296	do	Waldoboro Water Co	1902	6	do	156	24
297	Walpole	E. M. Woodman	1905	6	do	110	6
298	Wiscasset	Lincoln Bailey	1905	6	do	100	0
299	do	S. B. Cromwell	1904	6	do	48	
300	do	John Dow		6	do	154	0
301	do	W. G. Hubbard	1890	6	do	76	7
302	do	Lincoln County (jail)		6	do	154	0
303	do	A. R. Smith	1905		do	80	6
304	do	J. P. Tucker	1904	6	do	50	20
305	do	Turner Center Creamery	1890	5	do	64	3
306	do	do	1905	6	do	95	
307	do	U. S. Government (custom-house).	1905	6	do	79	24
	Oxford County.						
308	North Fryeburg	L. W. Atkinson	1890		Drilled	115	17
309	North Norway	Charles A. Merrill			do	62	
310	do	do	1891		do	102	7
311	Rumford Falls	C. M. Bisbee and R. J. Virgin	1901	8, 6	do	73	20
312	do	Rumford Falls Light and Water Co.	1904	2½	Driven	22–35	n. r.
313	South Paris	J. Frank Howland	1890	12	Drilled	122	50
314	do	Mason Manufacturing Co	1906	6	do	117	42
315	do	George R. Morton	1906	6	do	52	0
316	Sweden	Walter Evans			do	89	6
	Penobscot County.						
317	Bangor	H. C. Chapman & Son (Bangor House).	1899	6	Drilled	290	50
318	do	City of Bangor (high school)	1906	6	do	217	
319	do	City of Bangor (Larkin st. school).	1906	6	do	188	
320	do	City of Bangor (Palm st. school).	1906	6	do	72	
321	do	City of Bangor (Union sq. school)	1906	6	do	203	
322	do	Eastern Maine Insane Hospital	1896	6	do	425	0
323	do	Foster & Scribner			do	57	0
324	do	F. L. Jones	1905	6	do	247½	14
325	do	Thomas McAlloan			do	77	
326	do	Maine Creamery Co			do	120	50
327	do	Morse & Co	1906	6	do	255	0
328	do	Penobscot County courthouse	1905	5	do	201	
329	Bradford	W. E. Bailey	1882	8	Bored	54	
330	do	J. J. Reeves	1895	8	Drilled	197	
331	do	H. T. Williams	1885	6	do	61	
332	Brewer	Eastern Manufacturing Co	1899	6	do	350	59
333	do	do	1899	6	do	250	
334	Carmel	H. W. Garland	1902	6	do	66	66
335	do	J. E. Hasey	1902	7	do	58	
336	do	O. A. Stevens	1900	6	Bored	75	
337	Charleston	Charles Elden			Drilled	50	10
338	do	Higgins Classical Institute		6	do	105	0
339	do	A. H. Mitchell			do	190	40
340	Corinna	N. Reed Packard	1904	7, 6	do	61	4
341	do	A. J. Richardson	1884	6	do	59	
342	do	P. H. Simpson	1888		do	108	3
343	Corinth	L. H. Sawyer	1890		do	70	0
344	Dexter	James Cole	1895	6	do	58	24
345	Dixmont	E. D. Rowell	1887	6	do	112	5
346	East Corinth	Northern Maine Packing Co	1899	6	do	465	8
347	East Newport	L. D. Babb	1887	6	do	79	0
348	do	J. B. Chadbourne			do	57	4
349	do	J. P. Chadbourne			do	63	
350	do	C. M. Loud	1883	6	do	55	9
351	Etna	H. L. Grove	1897	6	do	54	6
352	do	G. B. Hibbard	1900	6	do	80	60
353	do	G. A. Sanborn	1890	6	do	57	56

Records of deep wells in southern Maine—Continued.

Depth to principal water supply (feet).	Depth to other supplies (feet).	Material in which water occurs.	Average height to which water rises (+ above, − below, well mouth).	Quality.	Yield (gallons per minute).	How obtained, where used.	Use, or if not used, the reason why.	No.
48	37	Granite	− 27	Soft	5½	Hand pump	Domestic	295
150	17	do	− 26		5	Not used	Never completed	296
106		Complex	− 12	Hard			Drinking and stock	297
90	35	do	− 20	Good		Windmill	Domestic and stock	298
		do	− 8	Little iron	5	Hand pump	do	299
		do				do	Drinking and stock	300
68	18	do	− 20	Hard	15±	Gasolene engine	Domestic and stock	301
		do		do		Hand pump	Drinking and stock	302
	15	do	− 10	Good		do	Domestic	303
		do	− 50	do		do	Domestic and stock	304
56		do	− 8	Salty		Abandoned	Salty water	305
		do	− 3	Brackish		Steam pump	Cooling cream	306
79	72	do	− 12	Hard	8	Hand pump	Domestic	307
			− 17	Hard		Windmill	Domestic and stock	308
					few	Hand pump		309
					few			310
25		Granite	− 20		few	Not used	Too little water	311
[a] 20		Sand and gravel.		Soft		Steam pump	Public supply	312
55		Complex	− 50			Not used	Too little water	313
		Granite	− 60	Good	40		Drinking and boilers	314
40		Complex	− 1	Soft			Domestic	315
79		Trap	− 17	Hard		Not used	Strong taste	316
280	−100	Slate	100	Hard	27	Pump	Hotel	317
		do		Good	many	Hand pump	Drinking	318
		do	− 8	do	30	do	do	319
		do		do	many	do	do	320
		do		do	many	do	do	321
425	50	do	−200	Good, hard	30	Steam pump	Domestic	322
		do		Good	many	Hand pump	Drinking	323
247½		do	− 22	do	many	do	do	324
		do		do	many			325
		do	− 10	do			Cooling cream and sold	326
255	17	do	+ 2	Soft, good		Hand pump	Domestic	327
60	80	do	− 50	Hard		Electric pump	Drinking	328
35		do	− 19	do		Hand pump	Public well	329
20		do	− 20	do	few	do	Domestic	330
58		do	− 15	do	1	do	Domestic and stock	331
21		do	− 21	Salty	1	Steam pump	Cooling acid	332
50±		do	− 20	Hard		do	do	333
50		do	− 16	do	2	Hand pump	Domestic	334
12		do	− 12	Soft		do		335
50		do	− 25	Hard	3½	do	Domestic	336
		do						337
100		do	− 8		15	Siphon	Domestic for 4 buildings.	338
		do		Good	many			339
61	20, 30	do	− 15	Hard	4	Windmill	Domestic and stock	340
59		do	− 18	do	3	do	Domestic	341
20		do	− 15	Hard, salty		Abandoned	Poor water	342
20	35	do	− 20	Soft		Hand pump	Farm	343
53		do	− 20	Hard	few	do	Domestic	344
112		do	few	Hard, alkaline		do	Domestic and stock	345
450		do	− 6	Sulphur and iron.	20	Steam pump	Drinking and canning.	346
70	35	do	− 15	Soft	30	Windmill	Domestic and stock	347
		do	− 55	Hard			Domestic	348
		do	− 17	do			do	349
		do	− 15	Fair		Hand pump	Domestic and stock	350
50	20	do	− 10	Soft	15	do	do	351
80	50	do	− 20	Hard		do	do	352
50	41	do	− 10	Little iron		do	Farm	353

[a] Average.

Records of deep wells in southern Maine—Continued.

No.	Locality.	Owner.	Year completed.	Diameter (inches).	Type.	Depth of well (feet).	Depth to rock (feet).
	Penobscot County—Con.						
354	Hampden	A. J. Bragg	1898	7	Drilled	103	.....
355	do	Cyrus Moulton	1901	6	do	85	.....
356	do	C. L. Philbrick	1899	6	do	50	20
357	do	J. E. Shaw	1889	6	do	100	2
358	do	Village of Hampden	1900	5	do	122	.....
359	Hampden Corners	J. F. Maddocks	.....	6	do	6 5	52
360	do	J. E. Shaw	1886	6	do	100	0
361	Hudson	Geo. H. Smith	1887	6	do	66	.....
362	Kenduskeag	Chester Weld	.....	.....	do	109	9
363	Newport	Frank Bennett	1889	6	do	53	.....
364	do	W. D. Crowell	1891	6	do	75	3
365	do	Edwin W. Trueworthy	.....	6	do	100	.....
366	North Dixmont	Thos. L. Bragden	.....	6	do	76	52
367	do	S. E. Harris	1896	4½	do	75	4
368	do	do	1897	5½	do	55	10
369	do	Chas. O. Varney	1895	6	do	55	50
370	Orono	N. W. Page	1903	....	Dug	54	n. r.
371	do	E. W. Mansfield	1890	6	Drilled	53	50
372	do	University of Maine	1886	6	do	54	25
373	Orrington	Archie Harding	1894	7	do	50	.....
374	Plymouth	H. M. Gage	1896	6	do	66	.....
375	do	H. W. Stackpole	1893	6	do	73	n. r.
376	Stetson	R. A. Fitts	.....	.....	do	100	.....
377	do	F. E. Wiggin	1878	12	do	74	0
	Sagadahoc County.						
378	Bath	Bath Iron Works	1885	4	Drilled	100+	.....
379	do	George Connell	1887	6	do	57	3
380	do	W. J. Donald	1883	6	do	167	.....
381	do	J. E. Dunton's heirs	1885	6	do	149	0
382	do	C. A. Hooker	1893	4	do	100	0
383	do	H. Langdon	1883	6	do	200	.....
384	do	Torrey Roller Bushing Works	1885	4	do	180	0
385	Bowdoinham	Mrs. George L. Hinckley	.....	.....	do	124	27
386	Five Islands	George E. Hughes	1900	6	do	242	0
387	Georgetown	William Wade	1904	6	do	270	1
388	McMahans Island	Sheepscot Land Co	.....	6	do	246½	.....
389	Pejepscot Mills	Pejepscot Paper Co	.....	.....	do	335	0
390	do	do	.....	.....	do	40	11
391	Popham Beach	— Tibbetts	.....	.....	do	962	.....
392	do	Fort Popham	.....	.....	do	91	.....
393	Richmond	Eugene Rankins	1885	5	do	42	.....
394	do	Frank Williams	1885	.....	do	65	0
395	Small Point	George O. Curtis	1904	6	do	100	.....
396	Woolwich	Lincoln Bailey	1905	6	do	98	0
397	do	F. W. Carleton	1892	6	do	98	0
398	do	J. Collins	1887	6	do	53	5
399	do	George G. Hathorn	1897	6	do	96	0
	Somerset County.						
400	Fairfield	F. C. Tobey	1884	8	Drilled	91	7
401	Norridgewock	F. H. Burrell	1901	6	do	77	.....
402	do	Guy C. Haynes	.....	6	do	26	10
403	Palmyra	Perry Furbush	.....	6	do	157	43
404	do	do	.....	.....	do	80	0
405	do	do	.....	6	do	80	0
406	Pittsfield	W. R. Hunnewell	.....	.....	do	47	.....
407	St. Albans	J. L. Palmer	1897	8	do	49	8
408	Skowhegan	Levi P. Weston	1880	.....	do	52	0
	Waldo County.						
409	Belfast	W. E. Whitcomb	.....	6	Drilled	81	.....
410	Belmont	Horace Chenery	1905	10, 8	do	187	12
411	Brooks	Jerome Geness	.....	.....	.....	51	.....

Records of deep wells in southern Maine—Continued.

Depth to principal water supply (feet).	Depth to other supplies (feet).	Material in which water occurs.	Average height to which water rises (+ above, K below, well mouth)	Quality.	Yield (gallons per minute).	How obtained, where used.	Use, or if not used, the reason why.	No.
90	40	Slate	−13	Soft		Hand pump	Domestic	354
78		do	− 5	Hard	1	do	do	355
30		do	−30	Hard, iron		Pump	do	356
95	25	do	−20	Medium		Hand pump	do	357
		do		Hard	5	Not used		358
65		do	−10		½	Hand pump	Drinking and stock	359
90	25	do				do	Domestic and stock	360
	42	do	−48	Hard		do	do	361
23		do		Iron	1	do	Domestic	362
29		do	−24	Soft		do	do	363
16		do	−16	Hard	many	do		364
70		do	−25	do		do	Domestic and stock	365
		do	−20	do		do	do	366
55		do	−22	do		Windmill	Domestic	367
44		do	−44	Poor		Hand pump	do	368
		do	few	Soft		do	do	369
30		Gravel	−30	Hard, good		Windmill	Domestic and stock	370
		Slate	−15	Hard		Hand pump	Domestic	371
52		do	few	do		Windmill and electric motor.	do	372
50		do		Good	many	Hand pump	Domestic and stock	373
		do	−30	Hard		Windmill	Farm	374
		Sand		Good		do	Domestic and stock	375
					0	Not used	No water	376
74		Slate	−30	Poor	few	Hand pump	Stock	377
						Abandoned	City water installed	378
50		Gneiss	− 3		4	Hand pump	Domestic	379
160		do	− 7	Soft	30	Abandoned	City water installed	380
			−30	Hard		Not used	do	381
60	20	Gneiss	− 0	do	40	Steam pump	Formerly used in boilers.	382
20			−20	Soft	1	Windmill	Domestic and irrigation.	383
50	130	Gneiss	−20	Hard		Steam pump	Bushing works	384
				do		Not used	Pump broken	385
242		Granite	−50	Soft	few	Electric-motor pump.	Domestic	386
					4			387
			−40	Soft				388
		Gneiss		Good	few	Hand pump	Domestic	389
		do	−24	do	many	do	do	390
						Not a well	Prospecting for coal	391
					12			392
16		Complex	−26	Hard, iron	2	Hand pump	Domestic	393
65		do	− 3	do		do	Stock and lawn	394
79					2			395
90	35	Complex	−20	Little hard		Abandoned	Poor water	396
		Gneiss		Hard	8	Hand pump	Domestic and stock	397
50	30		− 7			do	Farm	398
		Gneiss	−30	Hard	6	do	Domestic and stock	399
		Slate	−10	Hard		Hand pump	Domestic	400
70		do	−35			Never used	Never installed; deep-well pump.	401
26		do	− 0			Siphon	Domestic and stock	402
		do			0	Not used	No water	403
					1/60	Hand pump	Stock	404
60		do		Hard	1/7	do	do	405
			− 7	Soft		Not used		406
41		Slate	− 8	do	⅔	Windmill	Dairy and stock	407
		do				Abandoned	City water installed	408
		Slate						409
		do	− 3		19	Steam pump	Domestic and stock	410
		do						411

Records of deep wells in southern Maine—Continued.

No.	Locality	Owner.	Year completed.	Diameter (inches).	Type.	Depth of well (feet.)	Depth to rock (feet.)
	Waldo County—Cont'd.						
412	Cape Jellison	Northern Maine Seaport R.R. Co.	1905	8, 6	Drilled	225	70
413	do	do	1905	6	do	158	99
414	East Northport	Mrs. Mark Mandall			do	64	4
415	do	Mountain Spring Water Co.	1900	6	do	168	65
416	East Troy	L. E. Prentiss	1885	8	do	65	25
417	Islesboro	E. R. Adams	1906	6	do	100	
418	do	John T. Atterbury			do	150	
419	do	George Bird	1902	6	do	78	28
420	do	R. A. Boit	1902	6	do	398	
421	do	F. E. Bond	1901	6	do	218	4
422	do	H. E. Bond	1902	5⅝	do	218	9½
423	do	J. R. Brackett	1898	6	do	50+	
424	do	Miss Caldwell	1901	6	do	266	5½
425	do	Mrs. W. H. Draper		6	do	165	5
426	do	Mrs. —— Draper	1899	5½	do	102	10½
427	do	W. P. Farnsworth	1900	6	do	70	
428	do	J. Murray Forbes			do	180	
429	do	D. Hatch	1901	6	do	66	13
430	do	F. W. Hatch	1902	6	do	63	0
431	do	P. D. Hatch	1902	6	do	60	8½
432	do	T. B. Homer	1892		do	120	
433	do	do	1897		do	200	
434	do	Islesboro Land and Improvement Co.	1890	6	do	149	5
435	do	—— Kissel			do	220	
436	do	H. A. Lewis	1900		do	75	
437	do	M. E. Lewis	1903	6	do	150	
438	do	Mrs. Minton			do	300	
439	do	H. W. Morse	1901	6	do	210	130
440	do	Leighton Parks	1901	5	do	65	
441	do	Charles Pendleton	1901	6	do	54	4
442	do	do			do	50	
443	do	W. S. Pendleton	1901	6	do	69	13
444	do	Pendleton Bros.	1890	5⅝	do	71	12
445	do	C. S. Pierce	1901	6	do	225	
446	do	Charles Platt	1901	6	do	125	7
447	do	Helen L. Pratt	1898	8	do	101	
448	do	E. S. Preble			do	70	
449	do	F. C. Shattuck	1900		do	90	
450	do	H. T. Sloan	1902	7½	do	198	
451	do	David H. Smith	1901	6	do	134	0
452	do	Town of Islesboro	1887	5⅝	do	73	7½
453	do	J. D. Winsor	1902	5⅝	do	252	56
454	Jackson	M. S. Hatch	1885	9, 6	do	53	5
455	do	E. E. Morton	1885	7	do	45	6
456	Kidders Point, Searsport	Northern Maine Seaport R.R. Co.			do	285	62
457	Monroe	Nathan Stearns	1890	7	do	61	47
458	Searsport	J. H. Kneeland	1882	6	do	50	4
459	do	David Nickels	1904	6	do	108	17
460	do	Northern Maine Seaport R.R. Co.	1905	8, 6	do	329½	105
461	do	Penobscot Coal and Wharf Co.			do	301½	80
462	do	Searsport House	1894	6	do	97	10
463	do	Town of Searsport	1886	6	do	100	6
464	do	N. W. Staples	1887	6	do	64	34
465	Stockton Springs	J. C. Lambert	1892	6	do	50	15
466	do	Northern Maine Seaport R.R. Co.	1905	8, 6	do	247	74
467	do	A. H. Soden			do	100½	
468	Winterport	S. Chase	1888	6	do	57	6
469	do	C. W. Nealey		6	do	115	15
	Washington County.						
470	Calais	F. N. Beckett		6		90	
471	do	W. A. Rideout	1882	5		49	49
472	Columbia Falls	A. H. Chandler	1905	4	Driven	46	n. r.
473	do	A. and R. Logie	1904	6	do	72	n. r.
474	Eastport	Seacoast Canning Co.	1903	6	Drilled	408	0

Records of deep wells in southern Maine—Continued.

Depth to principal water supply (feet).	Depth to other supplies (feet).	Material in which water occurs.	Average height to which water rises (+ above, − below, well mouth).	Quality.	Yield (gallons per minute).	How obtained, where used.	Use, or if not used, the reason why.	No.
225		Slate	−20		200	Electric motor	Locomotives and ships	412
158		do			12	Abandoned	Supply insufficient	413
		Schist	− 1	Hard			Domestic	414
112	75, 100	do	−50	Soft	27	Steam pump	Public supply	415
40	52	Slate	−53	do		Hand pump		416
		do			15			417
		do		Good	15			418
35		do	−30	Hard	3	Hot-air engine	Domestic	419
394	200±	do	−15	do	10	do	Domestic and irrigation.	420
218		do	−40	do		Power pump	Domestic	421
218		do	− 4	Medium	16	Steam pump	Domestic and stock	422
		do		Hard	8	Hot-air engine	do	423
260	55	do	− 7	Medium	14	Steam pump	Domestic	424
90		do		Hard		Hand pump	do	425
99		do	−11	Medium	16	Gasoline engine	do	426
20		do	− 0	Hard	3	Hand pump	Stable	427
		do		Good	20		Domestic	428
30		do		Hard	8	Gasoline engine	do	429
57		do	−17	do	4	Hot-air engine	do	430
31		do	− 4	Soft	1½	Pump	do	431
		do	−10	Hard	1	Steam pump	do	432
	50	do	−few	do	1½	Hand pump	do	433
		do		do	8	Hot-air engine	Hotel and 10 cottages	434
		do		Good				435
		do	−20	Hard	4	Hot-air engine	Domestic	436
150		do	− 8	do	12	do	do	437
		do			few			438
		do	−50	Hard		Hot-air engine	Domestic	439
		do	− 3	do	5	do	do	440
24		do	−12	do	4	do	do	441
		do		Salty				442
22		do		Iron	6	Hand pump	Store and mill	443
70		do	− 5	Soft	5	Steam pump	Gristmill	444
		do	− 6	Hard		Hot-air engine	Domestic and stock	445
120	60	do		Soft	14		Domestic	446
20		do	−10	do		Gas engine	do	447
		do			many			448
		do	− 5	Hard			Domestic	449
190		do	+ 0		12	Hot-air engine	do	450
75		do	−20	Hard	10	Hand pump	do	451
73		do	−12	do	3	do	Public well	452
252	125	do	+ 0				Domestic	453
50	25	do	−20	Hard, iron		Windmill	Domestic and stock	454
	13	do	−13	Hard		Hand pump	Farm	455
284	80	do	−16	Soft	75	Electric power pump.	Locomotives and drinking.	456
		do	−41	Hard, iron		Pump	Domestic and stock	457
50	24	do	−20	do		Hand pump	Drinking and stock	458
	60	do	−19	Soft	20	do	Domestic	459
329½		do	−20	do	60	Steam pump	Locomotives	460
300		do	−12		50		Domestic and boilers	461
30		do	+ 0	Good		Windmill	Hotel	463
100		do	− 8	Hard, iron		Pump	Public well	462
64		do	−24		4	Hand pump	Domestic and stock	464
40		do	−25			do	do	465
247	187	do	−32			Steam pump	Locomotives	466
		do						467
53	30	do	−30	Hard, iron		Hand pump	Domestic and stock	468
115		do	−50			do	Stock	469
40			few			Not used		470
49			−20	Soft		Pump	Domestic	471
		Gravel	−12	Hard	4	Windmill	do	472
68	50	do	−20	Soft	3	Steam pump	Canning factory	473
345	408	Green stone	+ 0	Good, hard	60	Gas engine	do	474

Records of deep wells in southern Maine—Continued.

No.	Locality.	Owner.	Year completed.	Diameter (inches).	Type.	Depth of well (feet).	Depth to rock (feet).
	Washington County—Continued.						
475	Jonesport	Seacoast Canning Co	1904	6	Drilled	384	0
476	Lubec	Lubec Sardine Co			do	165	40
477	do	W. J. Mahlman	1893	6	do	100	
478	North Lubec	Seacoast Canning Co.[a]		6	do	60–70	
479	Pembroke	Gardiner Brick Co	1898	0.5	do	85	
480	do	Sprague & Wyhe		0.5	do	90±	
481	Roque Island	George A. Gardiner			do	90±	
	York County.						
482	Alfred				Drilled	140	0
483	Berwick	Benjamin Bragdon estate			do	65	18
484	do	C. E. Marshall	1898	6	do	80±	30
485	Buxton	J. M. Hopkinson		6	do	46	0
486	Cape Neddick	C. B. Moseley	1894	6	do	28	
487	do	W. H. Wentworth	1889	6	do	70	16
488	Fortune Rock	J. G. Brackett	1893		do	97	0
489	do	—— Davis	1889	6	do	100	
490	Gerrish Island	S. E. Jennison	1898	6	do	58	4
491	Kennebunk	Boston and Maine R. R.	1892	6	do	120	
492	do	Dr. Ross	1893	6	do	100±	
493	Kennebunk Beach	C. W. Arnold		6	do	80	
494	Kennebunkport	John W. Deering		6	do	50	
495	do	—— Giles	1886	6	do	75	
496	do	—— Hall	1886	6	do	75	
497	do	Kennebunkport Seashore Co	1889	6	do	55	
498	do	—— Smith	1885	6	do	60	
499	do	B. S. Thompson	1885	6	do	70	
500	Kittery	U. S. Government (navy-yard)			do	200	
501	do	do			do	300	
502	Kittery Point	Horace Mitchell		6	do	60	
503	do	Pepperell House		6	do	51	10
504	do	John Thaxter	1887	6	do	125	0
505	do	Roland Thaxter			do	75	
506	Lebanon Center	N. B. Shapleigh	1893	6	do	50	20
507	Limerick				do	100	
508	North Berwick	A. P. Littlefield			do	125	5
509	Ocean Bluff	Arlington Hotel			do	50±	
510	do	Sarah Bancroft	1884	6	do	73	2
511	do	Mrs. Samuel H. Jones			do	224	
512	do	Kennebunkport Seashore Co			do	85	0
513	do	Ocean Bluff House			do	102	
514	Ogunquit	Edward Freeman			do	68	15
515	do	Charles C. Hoyt estate	1890	6	do	65	5
516	Saco	City of Saco	1886	6	do	250	
517	do	Mason & Durgin		8		56	n. r.
518	do	W. Warren Co				61	n. r.
519	Wells	A. P. Littlefield			Drilled	100	
520	York	Hugh Talant		6	do	90	0
521	York Beach	Dr. Clement			do	59	
522	do	C. W. Hildreth		6	do	60	0
523	do	C. B. and W. C. Hildreth	1894		do	60	16
524	do	York Beach Water Co		6	do	60	2
525	York Harbor	E. S. Marshall	1888	6	do	325	0
526	do	York Harbor Hotel	1888	6	do	150	

[a] Three wells.

Records of deep wells in southern Maine—Continued.

Depth to principal water supply (feet).	Depth to other supplies (feet).	Material in which water occurs.	Average height to which water rises (+ above, − below, well mouth).	Quality.	Yield (gallons per minute).	How obtained, where used.	Use, or if not used, the reason why.	No.
		Diorite	− 7	Hard	2½	Hand pump	Drinking	475
		Greenstone			0	Not used	Very little water	476
96		do	−12	Good	1	Abandoned	City water installed	477
		do	− 1	do		Windmill	Canning factory	478
								479
				Good				480
				do		Gasoline engine	Domestic	481
39			−34			Not used		482
65		Slate	−12	Poor	many	Abandoned	City water installed	483
		do	+ 0			do	do	484
42	30		−24	Hard	few		Domestic	485
27		Slate	+ 0	Soft	30	Pump	do	486
		do	+ 2½	do		Windmill	Supplies 25 families	487
97		Granite	−20		⅓	do	Domestic	488
100	95				few		do	489
56	30	Slate	− 6	Soft	5		do	490
120			− 3		24			491
100±		Granite			10			492
			−20			Not used	City water installed	493
			−10		few	Hand pump	Domestic	494
								495
								496
50				Soft	3	Not used	City water installed	497
					few		Domestic	498
					few		do	499
		Slate			0	Not used	Nearly dry	500
					15			501
		Slate	− 7½	Soft	1	Windmill	Hotel	502
15		do	− 5	do	½	Not used	Hotel abandoned	503
110		Trap	−14	Hard	½	do	Too little water	504
		Slate		Iron		Hand pump	Domestic and stock	505
45		do	−40	Hard, iron	1	do	Domestic	506
				Surface water				507
122		Granite	−10	Soft	few		Stock	508
		Slate				Abandoned	City water installed	509
					8	do	do	510
224	90	Slate		Iron	few	do	do	511
		do				do	Hotel burned	512
		do				do	Failure	513
65		Granite			few			514
65		Slate	− 5	Hard	10+	Hot-air engine	Domestic, stock, and boilers.	515
250		do	−20		10	Windmill	Fountains	516
56		Gravel	+ 0			Abandoned		517
		do	+ 0					518
50		Granite						519
89½		Slate		Brackish	5	Not used	City water installed	520
		Granite	+ 0		40	Pump		521
60		do	−14	Hard	few	Hand pump	Domestic and stock	522
60		Slate	−18	do		Windmill	do	523
60		Granite	+ 2		84	Abandoned		524
325			−30	Salty	16	Not used	Too salty	525
		Slate				do	Not enough for hotel	526

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